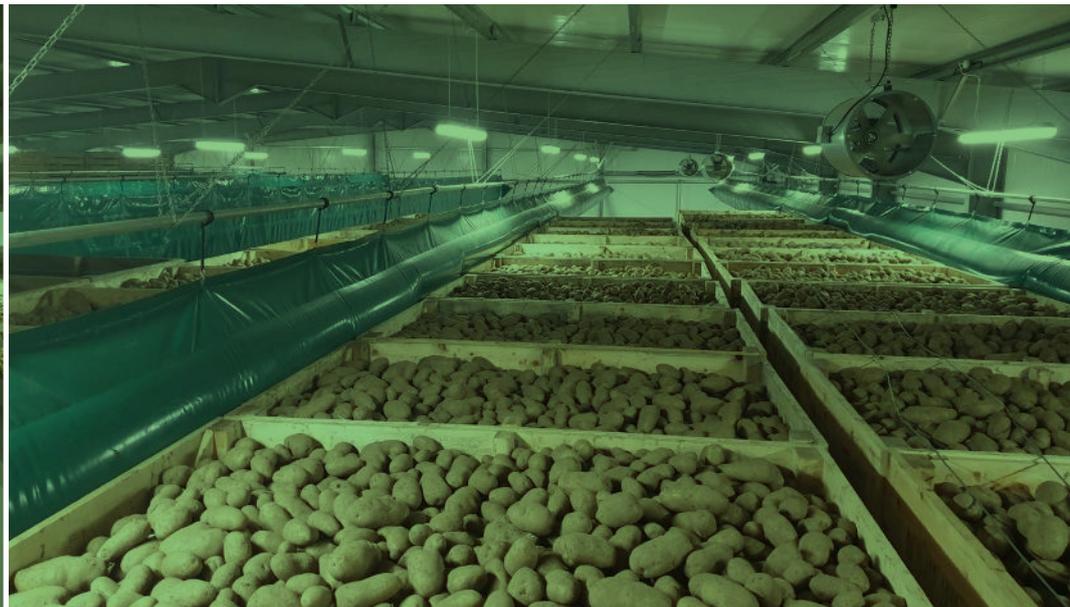




THE POTATO STORAGE HANDBOOK

2025 EDITION



Compiled by Adrian Cunnington and Stephanie Cornwall
Published by Warners Group Publications
in association with Potato Storage Insight Ltd



GLOSSARY

Air mixing/blending	Mixing or blending of recirculated and ambient air controlled by regulation of the duct temperature
Air-on/air-off TD	Temperature difference (TD) between air coming on and off a fridge coil
Ambient air	Air external to the building structure
Anaerobic conditions	Where no oxygen is present
Blemish diseases	Diseases which cause unsightly marks on the skin of the tuber
Bloom	Reflective shine on tubers
Composite panel	Factory-made insulation panel with a core made of polyisocyanurate (PIR) injected between two metal skins
Crop set-point	Target or desired crop temperature
Curing period	See wound-healing period
Dead band	Tolerance either side of a crop set-point
Dew-point	Temperature at which water vapour in air will start to condense
Differential	Difference in temperature between one area in a store and another, e.g. crop/ambient air differential would be the difference between the temperature of the crop and air drawn from outside
Disease expression	Display of visible disease symptoms
Disease infection	Entry into the flesh of the tuber by bacteria or fungus
Dormancy	Period between tuber initiation in the soil and growth of sprouts
Dormancy break	When 50% or more of tubers have sprouts of 3 mm or more in length
Duct lower limit	Minimum allowable temperature of air in main duct
Fridge TD	Temperature difference (TD) between air coming onto coil and evaporating gas temperature within the fridge coil
Hot box	Insulated cabinet warmed to 32–36°C, and humidified with water, used for samples of potatoes to speed expression of bruising or to accelerate rotting
Inoculum	Infective agents of disease, e.g. fungal spores, bacteria, etc.
Interstitial condensation	Condensation forming within the building structure
Latent heat of evaporation	(Hidden) heat required to change water from liquid phase to vapour phase with no increase in its temperature (2.4 MJ/kg). Half of cooling of potatoes with cool air results from heat removed by evaporation
Lateral (duct)	Secondary delivery duct off main air duct, usually beneath a bulk pile
Mummify	The process of drying a rotten tuber to a dry shrivelled mass
Periderm	Corky outer skin layer of potato
Relative humidity (RH)	Mass of water vapour in air at a defined temperature, compared with the maximum vapour it can hold at that temperature, expressed as a percentage
Saturation	Point where air contains the maximum mass of water vapour which can be held per unit mass of air at any given temperature (=100% RH)
Soft rots	Bacterial wet rots
Split-grading	Separating tubers into two or more size fractions, usually at harvest
Stack condensation	Condensation forming within the crop
Structural condensation	Condensation forming on the building structure
Suberisation	Laying down of the chemical suberin between damaged surface cells of tuber as first part of periderm formation in the natural wound healing process
U-Value	Heat conductivity of a building material (W/m ² .°C). Lower value = better insulation
Wet rots	Tubers where the flesh has been invaded by disease organisms to form a liquid mass with little structural strength. The wet mass collapses on unaffected neighbouring tubers, providing inoculum and anaerobic conditions, which can lead to further rotting
Wound-healing period	Period for wounds on crop to heal, to form a barrier against disease ingress to the flesh of the tuber

Introduction

STORAGE of potatoes plays an important role in the potato supply chain, and in-store practices can make all the difference to the quality of crop that is ultimately delivered to a customer.

There are many risks associated with potatoes in store, including the onset of diseases like soft rot, sprouting, and greening. Managing those risks is just one of the challenges affecting store managers.

At the same time, the increase in energy tariffs witnessed in recent years, means the need to operate stores efficiently, while minimising associated running costs and maximising returns, is an uphill struggle. New technology and equipment to help with store monitoring and maintenance is also changing year-on-year.

Good storage control covers everything from servicing and calibration of equipment before use, through correct loading procedures, to optimised operation of ventilation systems and monitoring of air flow and leakage.

Store management is a complex process therefore, with multiple points at which problems and inefficiencies can occur and jeopardise the prospect of success.

In this guide, we go through each step of the store management process, outlining what's involved and how to handle this most efficiently, to help those managing and operating potato stores to get the best results.

We also highlight some of the field-based factors that can also influence decisions in store, from variety choice, issues leading to dormancy break and sprouting, and adequate 'set' skin.

Adrian Cunnington

Adrian Cunnington has spent more than 35 years working in applied research, knowledge transfer and best practice advice on all aspects of potato storage. An industry consultant, trainer and facilitator, his name is synonymous with potato storage. Having headed up the Sutton Bridge Crop Storage Research facility from 1989 until its closure in 2021, he now runs his own consultancy and collaborates on industry initiatives and training days. Himself a winner of the British Potato Industry Award 2023, he is also now on the judging panel of the British Potato Industry Awards.



Stephanie Cornwall

Stephanie Cornwall has edited British Potato Review magazine and its associated digital platforms since 2018. In that time, she has extended its readership and content, introducing designated focus sections on all field activities through to legislative and market impacts, and supply chain considerations. Having helped to launch the British Potato Industry Awards scheme in 2019, she is also a member of its judging panel and a long-time supporter of the British Potato Industry Event.



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Storage buildings

IF a potato store is well-sealed and insulated, it will allow the crop to be kept at a stable temperature that is largely unaffected by diurnal (daily) variation in ambient conditions.

Tuber weight loss will be minimised as it will help maintain a relative humidity of 90–100% and it will also allow crops to be stored free from condensation in changeable weather conditions.

Storage is usually undertaken in bulk or in boxes. The capital cost of a bulk store with load-bearing, insulated retaining walls is higher than that of a box store. However, when the capital cost of boxes is added, box storage will be more expensive overall.

Positive ventilation will be beneficial to deep bulk piles but pressure-bruising problems can occur if the crop is stored more than 4m deep or is excessively ventilated.

Box storage is more complex to ventilate uniformly. However, box stores help with separation of different stocks and provide more flexibility for crop movement and marketing.

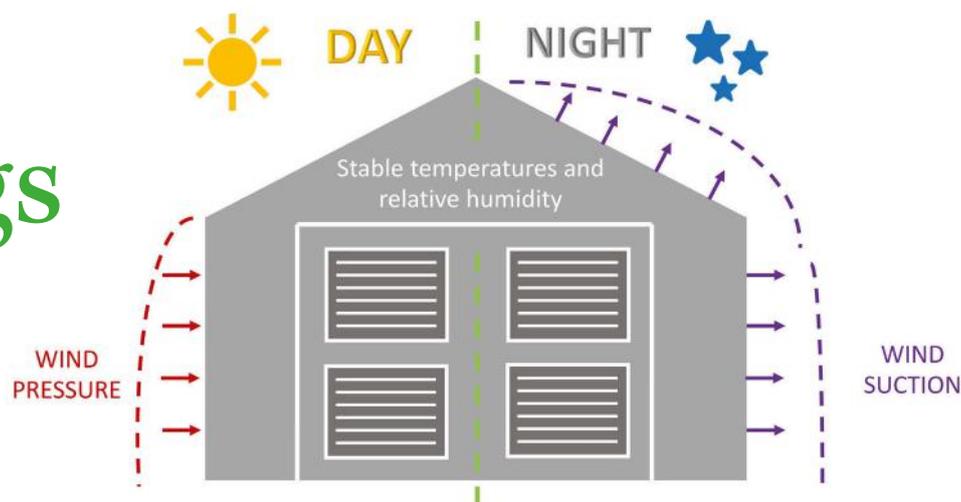
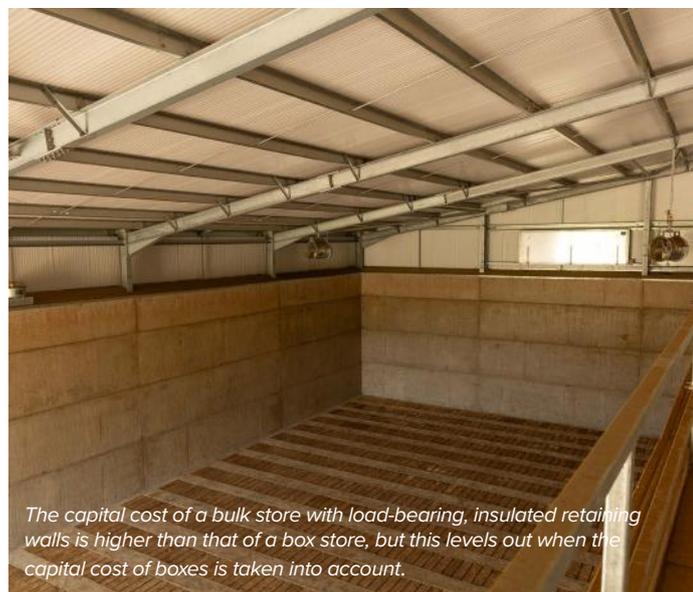
Depending on their size, age and quality, boxes can be stacked up to eight high.

Controlled ventilation

Crop respiration heat can be removed, and the potato crop dried and cooled, by controlled ventilation.

A good flow of air through the crop (positive ventilation, bulk or box) can be created by the use of fans or, less efficiently, to form a rolling mass of air that flows over the stack of boxes and through the pallet slots (space ventilation).

Cooling can be achieved using ambient air and/or mechanical



The building envelope has to minimise the impact of external climate on the stored crop.

cooling (refrigeration). Internal recirculation of air (without cooling) can be used to eliminate temperature variation or to distribute chemicals for sprout suppression or disease control. Airflow should be as uniform as possible throughout the store, to give even drying and stable crop temperatures.

A well-designed store will have been balanced to achieve uniformity of airflow at its typical operating condition. This might include features such as tapered air ducts or graduated lateral outlets to deliver similar quantities of air across the whole store.

Computer-aided (CFD) options now enable optimised ventilation designs for new and retrofit installations.

Quality of insulation

How well a potato store performs will largely depend on the quality of the insulation, which is an even more important factor in a potato store than it is for general-purpose buildings.

While it's not usually a problem to maintain temperatures above freezing point owing to the quantity of heat produced in a large store, any heat that leaks into a store has to be removed by ventilation or refrigeration and this can add to the cost of electricity.

As well as the cost implications, the avoidable operation of environmental control equipment will always increase water loss from the crop. It's therefore worthwhile using insulation to limit heat ingress into the store as well as taking measures to minimise the effects of cold weather.

A light-coloured, reflective, external surface will reduce unwanted solar radiation gains.

Nearly all insulation materials have their performance reduced significantly by small increases in their moisture content. The use of vapour barriers to protect insulation is only effective in the high humidity conditions found in potato stores where composite metal/polyisocyanurate (PIR) sandwich panels are used. These are commonly used for newly-built stores at thicknesses of up to 120 mm.

Other systems for upgrades offer, at best, little more than a vapour check. This tends to limit the choice of insulation to either spray or board polyurethane or, occasionally, EEP board (e.g. Styrofoam). If moisture 'drive' across insulation cannot be prevented, or if the insulation is inadequate, condensation will form within or on the structure, reducing its effectiveness and risking moisture deposition on the crop.

BUILDINGS

It's advisable to seek specialist advice on air linkage. A specialist will be able to carry out an air leakage test to assess the building's performance.



A specific air leakage test for stores has been developed to assess buildings' relative performance. This uses a fan system to generate an AP50 value for each store. This is a measurement of the leakage when the building envelope is subjected to a differential pressure of 50 pascals.

An AP50 of $\leq 3 \text{ m}^3/\text{h.m}^2$ is regarded as an acceptable standard for new buildings. Existing buildings, even good ones, may not achieve this. A threshold of $\leq 10 \text{ m}^3/\text{h.m}^2$ is more realistic.

It is strongly recommended that specialist advice be sought for all aspects of storage building design.



Box stores help with separation of different stocks and provide more flexibility for crop movement and marketing.

Air leakage

Fabric or door leakage to wind-induced ventilation reduces the effectiveness of the store, as it is likely to lead to loss of environmental control. Crop weight loss and possible condensation on the crop will result as ventilation or refrigeration running hours will increase in order to cool the crop warmed by the leaking air.



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Stored crop



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Crop physiology for storage

Respiration

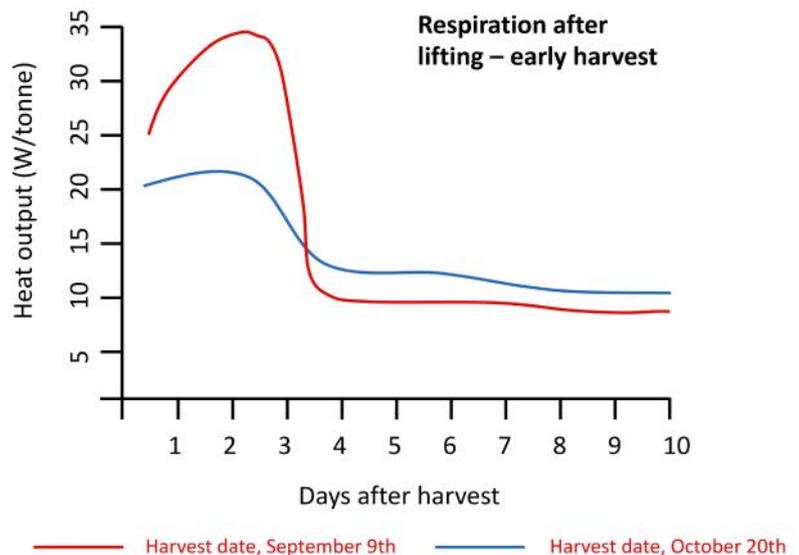
AS living organisms, potatoes continue to respire and respond to their environment when they are in a store.

Sugars from starch are used in their respiration process. Oxygen is consumed and carbon dioxide released along with some heat energy, which impacts on storage systems.

Respiration is highest after harvest and falls rapidly to a basal level in the first weeks of storage.

Respiration is greater in early-lifted, immature crops than in late-lifted, mature crops.

Although basal respiration rate depends predominantly on storage temperature in the period after harvest, research has shown that temperature has a less significant effect later in storage.



Evaporation

Whilst some moisture is lost in the respiration process, most is lost by evaporation from the tuber surface. Effective wound healing and sprout control are therefore important in limiting water loss from tubers.

Moisture loss is a function of store humidity and airflow rate, although this process is regulated by the permeability of the skin of the potato.

Over time, well-sealed potato stores will equilibrate to approximately 95–98% relative humidity, although, in the absence of humidification to add moisture to the store air, this will be derived from evaporation.

Leaky stores may never achieve this, but, in lower humidity air, weight loss will be higher.

Dormancy

Freshly-harvested tubers usually do not sprout, even when conditions are optimal for sprout growth. The period over which sprout growth is inhibited by the tuber's physiology, rather than the environment, is termed the dormant period or simply 'dormancy'.

Large differences in dormancy occur between varieties. Warm storage temperatures have a dormancy-breaking effect. Selection of varieties with longer dormancy can be useful for minimising sprout suppressant input.

Dormancy break is taken as the point where 50% of tubers have sprouts of 3mm or more in length. Warm, dry summers tend to reduce dormancy (in extreme cases leading to sprout growth in the field before harvest), while cool growing conditions will generally prolong it. Waterlogging breaks dormancy.

CROP PHYSIOLOGY

Healing of wounds

Where tubers have been subjected to wounding (e.g. by handling during harvest), the tuber will attempt to heal the wound – this involves both suberisation (which forms an impermeable barrier to moisture loss) and cell division. The speed of this process (curing), which is also important for preventing disease ingress, is affected by factors such as storage temperature and humidity, with warmer temperatures and higher humidity generally reducing the time required for wound healing.

The need for specific action is often greatest in crops harvested late, in wet or cold conditions, when some supplementary heating may be required to achieve effective curing.

Sugars and conditioning

Potatoes contain three main sugars: Glucose and fructose (monosaccharides/reducing sugars) and sucrose (a disaccharide). All three are sweet and important flavour components in ware potatoes.

Where potatoes are destined for frying, quality is determined by the reducing sugars as these react on cooking to produce browning (fry colour). Trends in sucrose levels can help identify when reducing sugars are low during storage.

Variety, growth stage and storage temperature are important in determining tuber sugar content. Potatoes exhibit low temperature sweetening, where sugars accumulate within the tuber as temperature is reduced.

During long-term storage for processing, temperature should, therefore, be maintained at the lowest level that safely maintains acceptable fry colour.

For processing crops, excess low temperature sweetening (and hence dark fry colour) may be reversed using reconditioning (warming prior to unloading). This is not the case for senescent sweetening, which results in a sugar increase when tubers age.

A by-product of the frying process is acrylamide, a recognised food hazard. Legislation was introduced in 2018 to mitigate levels of acrylamide formation in a range of foods.

Greening and glycoalkaloids

Tubers exposed to light turn green because of the synthesis of chlorophyll pigment. Chlorophyll is harmless, but green tubers are generally rejected because they have elevated levels of glycoalkaloids, a group of natural toxins present in potatoes.

To prevent greening in storage, exposure to light must be minimised. However, the need to inspect the crop, health and safety access requirements will override this during loading and subsequent short periods when stores are accessed for monitoring or sampling.

Use an external alert to prevent lights being left on in store.

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WHILE few potato diseases originate in store, controlling disease is a fundamental component of storage management.

Seed and soil are the two primary sources of disease. However, many of the disease problems affecting the premium markets can develop to some degree in store and, if not controlled, can result in catastrophic consequences leading to physical breakdown of the crop or loss of market value.

There are three key factors which will determine whether or not disease develops on stored potatoes. These are:

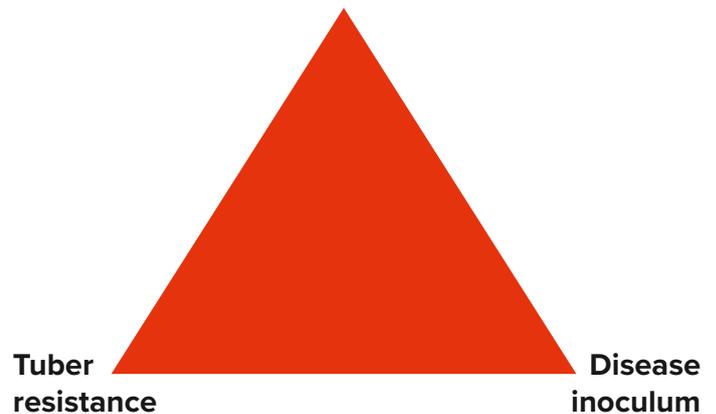
- The amount of disease inoculum, usually spores or bacteria, present on the tubers
- Whether moisture, nutrients and temperature are suitable for the disease to develop (microclimate)
- The natural resistance of the tuber to the disease organism. This includes having a robust set skin, so effective defoliation is important for disease control

Store management influences this interactive relationship, particularly in regard to the microclimate around the tuber, in order to control diseases during storage.

Skin spot.



Environment/microclimate



Best practice

Even with the use of clean seed and resistant varieties, there are few storage scenarios that don't feature potential disease hosts. Good skin set is crucial, as disease inoculum is often present and control of the microclimate is essential for management of disease risk.

The following best practice measures can help to reduce opportunities for disease development:

- Ensuring robust skin sets via timely burn down
- Efficient harvest, allowing store to be closed quickly
- Optimised airflow for effective drying and cooling
- Avoidance of condensation
- Good store and grader hygiene

Notifiable diseases

Some diseases are not indigenous in Britain and their establishment would affect the long-term viability of the potato industry. If symptoms of either brown rot or ring rot are suspected, then immediate notification to Animal & Plant Health Agency (APHA) is necessary.

Visit www.gov.uk/government/organisations/animal-and-plant-health-agency

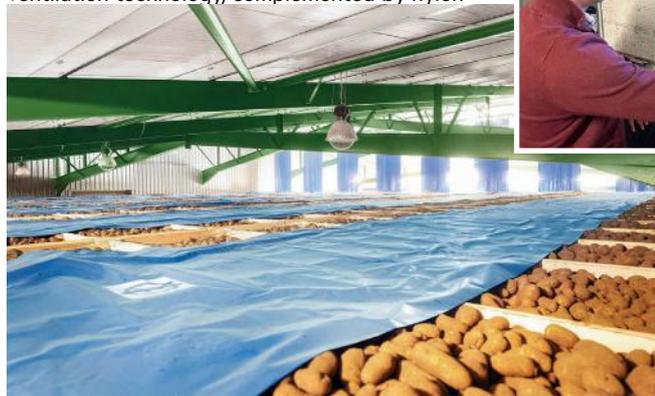
How advanced storage delivers superior potato quality

When PJ Lee & Sons invested in an advanced 12,000-tonne potato store with suction ventilation system, the benefits quickly exceeded expectations.

Originally installed to ensure crop quality through precise climate control, the system proved invaluable when Covid-19 disrupted markets. Despite potatoes being stored for more than 13 months, the crop remained virtually indistinguishable from freshly-harvested produce.

Financial Director at PJ Lee & Sons, Christopher Lee, said: "Potatoes can't be improved once harvested, but our Omnivent storage system ensures we preserve maximum quality. Where yield losses during storage for the industry are typically 12-14%, we average 7% for the season. That's a lot more saleable crop."

Critical to the success is the unique suction ventilation technology, complemented by nylon



curtains sealing air paths through potato boxes, ensuring even airflow. This method enhances treatment distribution, conserves energy, and minimises weight loss. The advanced CO₂ recuperation and humidity control significantly reduces electricity costs and enhances safety by eliminating the need to vent CO₂ externally.

"The Omnivent system has put our name on the map for produce quality, and we receive many more enquiries from buyers across the UK and abroad," says Lee.

Although the initial investment was around 20% higher than traditional systems, the return on investment arrived five years earlier than expected, prompting further storage upgrades across older facilities.

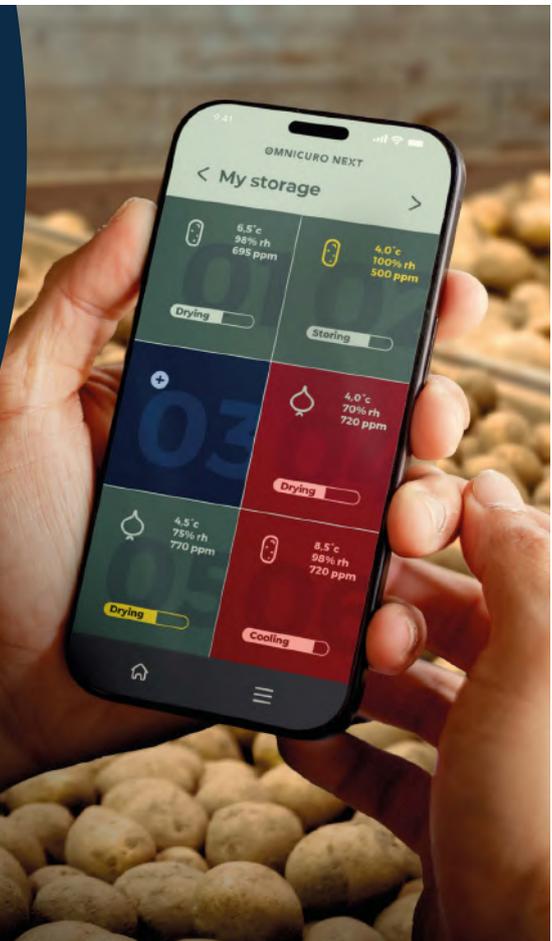
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DISEASE CONTROL



Dry rot.



Hollow heart.



Late blight damage.



Root and stem rot.



Skin spot.



Sprout suppressant scorch.

Pre-storage control

	Silver scurf	Black dot	Skin spot	Dry rot	Gangrene	Pink rot/ watery wound rot	Soft rot
Healthy seed	✓	✓	✓	✓	✓	✓	✓
Long rotation	✓	✓	✓			✓	
Short growing season	✓	✓			✓		
Early harvest	✓	✓	✓		✓	✓	✓
Variety susceptibility			✓	✓	✓	✓	✓
Minimise damage			✓	✓	✓	✓	✓
Dry harvest	✓	✓	✓	✓	✓	✓ but cool	✓

Control during storage

	Silver scurf	Black dot	Skin spot	Dry rot	Gangrene	Pink rot/ watery wound rot	Soft rot	Silver scurf
Curing			✓	✓	✓			
Immediate pull-down	✓	✓					✓	✓
Fast pull-down	✓	✓					✓	✓
Low holding temperature	✓	✓		✓			✓	✓
Minimise damage	✓		✓	✓				
Store hygiene	✓		✓	✓			✓	✓

Diseases and defects

BOTH diseases and defects can significantly impact the quality and marketability of potatoes. Defects can be physiological or environmental.

To assess blemishing, it is useful to visualise what 10% of a tuber's surface area looks like. This can be done by taking a marker pen and drawing three opposing equators on a potato, dividing it into eight triangles. A large circle drawn inside the triangle is roughly equivalent to 10% of the potato.

To choose an appropriate sample size, it is useful to set a threshold incidence, above which a load would be rejected. Accurate estimation of the level of disease or defect requires sampling three times as many tubers at the chosen threshold. Samples must be representative of the whole crop.

Maximum permitted defect threshold %	Minimum sample to detect defect
20	15 tubers
10	30 tubers
5	60 tubers
2	150 tubers
1	300 tubers

BLEMISH DISEASES

Silver scurf:

Silver scurf appears as silvery-grey patches on potato skins, which can darken and develop a sooty, black, speckled appearance during storage. These patches are caused by the outer skin layer splitting and separating, and under moist conditions, the surface can become covered in fine black dots

Black dot:

Black dot disease appears as small, irregular lesions that give the potato a "sooty" or "rash-like" appearance, sometimes developing into a silvery sheen during storage.

Skin spot:

Skin spot appears as raised, dark grey spots on the tuber's skin, often surrounded by a sunken ring. Skin spot is encouraged by inadequate curing and cool temperatures. It can reduce market value.

Common scab:

Common scab appears as raised, rough, cork-like patches on the skin, ranging from small, light-coloured spots to larger, dark, irregular areas that can be pitted or cracked. Angular edges and star-like cracking can sometimes be seen. The flesh underneath is usually unaffected.

Powdery scab:

Powdery scab appears as small, raised, brown pustules on potato tubers that can merge into irregular patches. Unlike common scab, lesions are more uniform in shape and are generally small and round. After the pustules erupt, they leave behind a mass of dusty brown spores and ragged, papery skin fragments.

Black scurf:

Black scurf appears as raised, irregular, and hard black patches on the skin that can be scraped off with a fingernail.

STORAGE ROTTS

Bacterial soft rot:

A potato with bacterial soft rot has a soft, watery, cream-colored to tan rot that progresses inward from the surface, often with a dark brown or black margin. Strong pungent smell and rapid breakdown. Can develop from blackleg in the field.

Dry rot:

A potato with dry rot will show wrinkled, brown patches on the skin, which correspond to a shriveled and hollowed-out area inside. Caused by damage in warm conditions/storage.

Gangrene:

Gangrene appears as dark, sunken, "thumbprint" shaped lesions on the surface with a sharp margin. The internal rot is a dark, dry rot, often with a distinct border.

Late blight:

Late blight in potatoes appears as small, pale-green, water-soaked spots on leaves that rapidly expand into larger, greasy, dark brown or black lesions with yellow halos.

Pink rot:

A potato affected by pink rot initially appears externally with soil that sticks firmly and may have loose skin or blackened lenticels, while the inside tissue is cream-colored and rubbery.

Watery wound rot:

Tubers have grey or brown lesions, skin look bruised, soft, and moist and have a sour or alcoholic smell, which can turn fishy or pungent. Diseased flesh is typically greyish-cream coloured, spongy and releases a clear or brownish, watery liquid.

TUBER DISORDERS

Mechanical damage:

Visible external injuries like cracks and scuffs will be seen, alongside hidden internal damage that manifests as black or grey discoloration of the flesh.

Bruising:

Bruising is caused by mechanical impact and forms a blackened area beneath the skin that is often invisible until the tuber is cut.

Growth cracks:

Growth cracks on potatoes appear as fissures that often start at the bud end and extend lengthwise, sometimes healing with a rough, corky, or callus-like covering.

Blackheart:

Blackheart potatoes have a dark grey to black discoloration that starts at the centre of the tuber. The outside of the potato usually appears sound. Blackheart is associated with oxygen depletion in the central tissues of the potato.

Anthocyanin:

Anthocyanin potatoes have a coloured appearance, typically violet, owing to the presence of natural pigments.

Rhizoctonia distortion:

Key appearances of Rhizoctonia distortion on potato tubers include malformed tubers, "Elephant Hide" or "Giraffe Neck" skin, cracking, dimples and trumpet-shaped holes and Sclerotia.

Violet root rot:

A potato infected with violet root rot will appear with a purplish-brown fungal mat or "web" on its surface, often with a network of fine, purplish strands that can form thickened cords up to 1mm wide.

Pit rot:

Pit rot in potatoes appears as small, round, dark, and sunken lesions on the tuber's skin, typically centered on a lenticel. Internally, the infection can extend into the flesh as a moist, dark brown, hemispherical rot radiating from the entry point.

Spraying:

Potatoes have internal brown arcs, rings, or flecks in the flesh, though the skin usually appears normal. External symptoms can include raised rings on the surface, but this is less common

Internal sprouting:

This defect is often not visible from the outside but if the internal sprout is growing close to the surface, there might be a slight bulge in the outer flesh, a small split in the skin or an area of tightly-wrinkled skin over the sprout. Can be caused by underdosing with sprout suppressant.

Hollow heart:

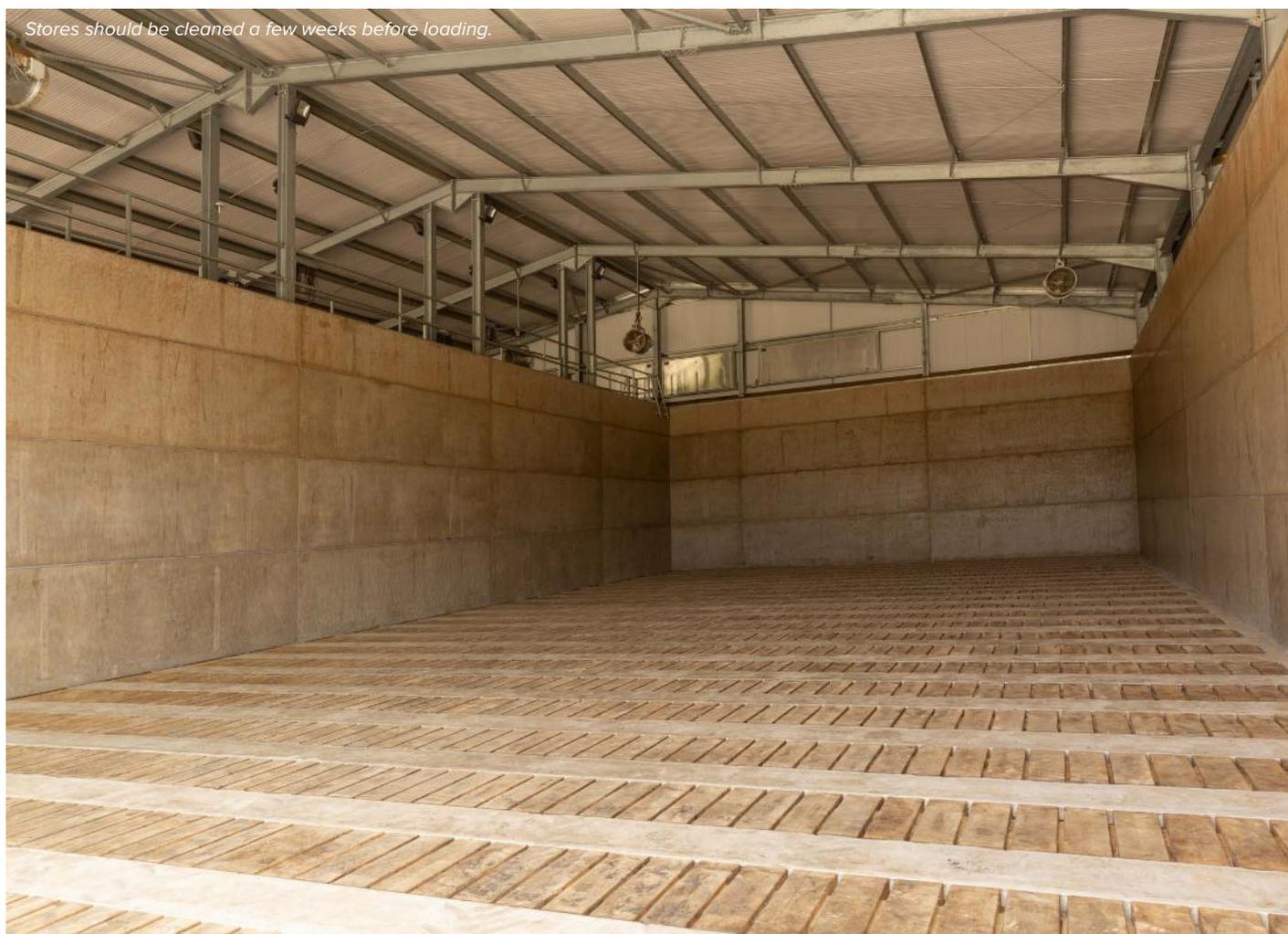
No external signs will be visible but there will be a hollow or lens-shaped cavity in the centre which is often lined with a reddish-brown, discolored tissue. The cavity can be small and hard to see or large enough to make the potato feel light.

Internal browning:

Dry, brown or reddish-brown spots and blotches are scattered throughout the flesh, or sometimes there will be a short discoloration along the central long axis of the tuber.

Slug damage:

Irregular holes appear on the tuber's surface, often with a slimy trail nearby, leading to larger, hollowed-out cavities inside the potato. The margins of these cavities may appear brown.



Preparation and hygiene

A KEY part of store preparation is to carry out an annual inspection of buildings and hardware, which can be done at the same time as store cleaning a few weeks before loading.

It's advisable not to leave this inspection until the last minute and to look for signs of fabric damage, before taking action to seal any gaps and repair any defective equipment encountered during the inspection.

Dispersal and removal of spores

Disease risk can be minimised if stores are cleaned annually. Ventilation and convection currents, caused by respiration heat from the crop, will circulate dust-containing disease spores throughout the store and cross-contamination of spores between potato stocks is inevitable.

Store activity such as forklift movement can also create major dust movement and dispersal, creating a dust cloud that will settle on top of the crop, where the risk of condensation needed for spore germination is greatest.

While sweeping with a brush will move the heavier dust particles along the floor, it will create a cloud of lighter particles, including the majority of spores. Vacuuming is the preferred method as it loosens and removes all fractions of dust and, if fitted with a fine filter, will remove most harmful spores from the store.

Hygiene and disinfection

The majority of disease inoculum present will be removed by clearing dust and stray tubers from storage areas and ducts and is usually adequate for most ware crops.

However, if wet rots have been a problem in the previous season, steam-cleaning of the boxes and affected areas of the store is recommended.

Where total removal of viable spores is required, for high-health crops, disinfectant can be used. This is particularly relevant in stores where bacterial soft rotting or damage-related fungal diseases such as dry rot have occurred. Most disinfectants will not work without prior cleaning and removal of dust and debris as they are deactivated by organic matter. Make sure any disinfectant used on parts of the store that are in contact with crops are food-safe and acceptable to your intended market.

Chemical residue removal

The CIPC Residues Monitoring Group gathers information on chlorpropham residues following the withdrawal of this persistent chemical in 2020. It is important to follow best practice for cleaning stores subjected to previous chemical treatments that may leave a residue in the store for years to come.

PREPARATION / HYGIENE



Vacuuming loosens and removes all fractions of dust and, if fitted with a fine filter, will remove most harmful spores from the store.

The building and ventilation infrastructure must be thoroughly cleaned, and boxes exposed to UV and outside air to maximise chemical breakdown.

Boxes

Leaving boxes outside will allow light to kill viable spores. Empty boxes should not be stacked more than four boxes high for safety and, if stacked in pairs, a small gap between rows will help natural (UV) light to reach every box. However, outside stacking can reduce box life by up to 40%.

Many box stocks now require annual replenishment to replace boxes at the end of their useful life. Ensure that an inspection of box condition is undertaken annually to identify those that are in need of repair or replacement.

Do not take risks with boxes in marginal condition as, if a stack collapses in store, the consequences can be significant for operator safety, store integrity or crop ventilation.

Servicing

Maintaining fans, ventilation and refrigeration coils in a clean condition will help prolong their life and improve their working efficiency. Routine servicing by specialists of refrigeration, cooling and monitoring systems will ensure reliable and efficient store operation during the winter and prolong equipment life. Refrigeration equipment, in particular, is too complex to be serviced by non-specialist personnel.

New regulations require some refrigerants to be replaced and leakage to be monitored, to minimise ozone depletion in the upper atmosphere, so it is important to ensure systems are legally compliant.

Sensors

Good store management should ensure crop temperatures are as uniform as possible to minimise the risk of condensation.

Sensors, therefore, need to be sufficiently accurate to measure differences as small as 0.5°C.

Regular verification against a calibrated, precision thermometer at ambient temperature and in melting ice at 0°C should be carried out to ensure any differentials measured are real and not due to sensor inaccuracy.

Always replace sensors that show any sign of damage to either the cable or probe. This includes stretched or compressed cables as, while these may give a reading, the electrical resistance of the cable may have changed as a result of it being damaged.

In both box and bulk stores, sensors should preferably be located in the top and bottom of the stack, with most located in the top of the crop and some at the base. Alkathene tube, e.g. water pipe, makes a good sleeve in which to fit sensors at low level in a bulk store; fit it on the face of the stack, rather than vertically.

The CIPC Residues Monitoring Group (CRMG) is a cross-industry body which has been set up by the UK potato industry to satisfy the data submission requirements of the Health & Safety Executive's Chemical Regulation Division (CRD).



It measures chlorpropham (CIPC) residues in potatoes held in potato stores previously treated with CIPC.

Stores with a CIPC history are at risk of being taken out of use if their operators do not provide the relevant data to show they can still be safely used and comply with minimum residue levels.

For more details about CRMG and CIPC levels compliance, email adrian@potatostorageinsight.com.



Store loading

Planning

When it comes to harvest, it is essential that there is a well-structured plan in place for any store loading operation. Storage is expensive but can play a major part in earning additional returns, so it is crucial to get the right crop into the right store. Plan ahead!

Crops going into store need to be harvested with little damage and minimal contamination from soil, stones and haulm. Ventilation needs to be implemented quickly to remove surface moisture from potatoes and to dry out any remaining soil.

Good field sampling ahead of harvest will identify any significant storage risks, such as diseases/rots or pest damage. Do not store crops which have been waterlogged or rained on. If water gets into the lenticels (breathing pores), it prevents respiration and bacterial breakdown is likely. Any crop with more than 1% or 2% rots should not be stored.

Mechanical damage at harvest should be avoided as it can affect the crop's integrity in two ways.

Make sure skins are fully set before trying to store a crop. Damage, including scuffing, increases the risk of moisture loss and also allows fungal and bacterial infections into the tuber. Routine assessment of damage is good practice and keeping samples overnight in a 'hot-box' to assess levels of bruising is also recommended.

As harvesting capabilities have increased in recent years with the introduction of self-propelled machines, for example, there should be less risk of extended loading times unless the weather intervenes.

Aim to load stores within a week wherever possible. Store capacities should fit in with this target. Very large stores may need to be subdivided.

Ventilation

Use positive ventilation whenever it is available in bulk stores or letterbox stores. This helps to reduce the risk of condensation. If forced ventilation is not available, take all possible steps to ensure the air passes through the boxes by closing off any short circuits. Air to crop contact is key to prevent field heat building-up when crops first enter the store.

During loading, it is best to allow the temperature of the crop in store to track the ambient condition outside so that, when crop comes into store, it is at a similar temperature. This avoids large temperature differences building up, which might otherwise cause condensation. As a guide, ventilate whenever the outside air is within 4°C of crop temperature to ensure crops are kept dry and free from re-wetting.

Make sure there is a good plan of the box stacking arrangements so that all personnel are familiar with it. Marking the floor to show the box layout is good practice.

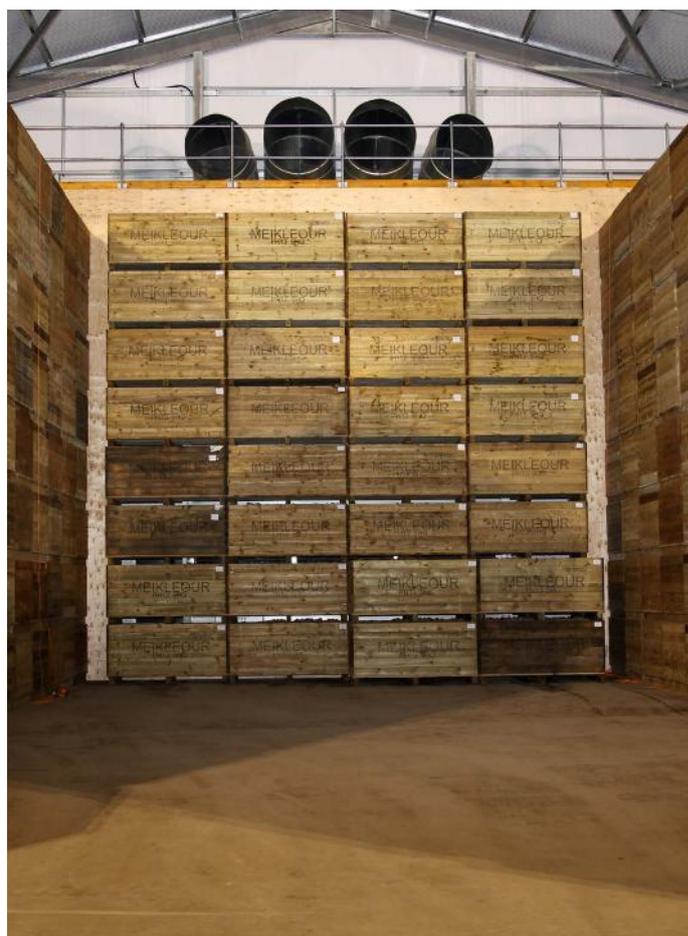
STORE LOADING



“Use positive ventilation whenever it is available in bulk stores or letterbox stores. This helps to reduce the risk of condensation.”

Most positive systems require boxes to be aligned with air outlets or plenum chambers. In space-ventilated systems, air distribution is required to all of the pallet slots to keep crop temperatures even and to distribute in-store sprout suppressant treatments. This requires a ‘roll of air’ around the store that should not be impeded by boxes being stacked too tightly or at 90 degrees to the air flow.

As a rule, allow a 450 mm gap between the main block and any ‘headland’ boxes. Leave a 50mm gap between every other box within the headland rows.



Ventilation

MOVEMENT of air through the potatoes is the main way in which the crop's condition can be regulated, via drying, cooling, heating, humidifying or adding chemical treatments. It's therefore critical to ensure the correct ventilation is available in storage.

Specific strategies are needed for key processes, such as drying and initial pull-down, to holding temperature and for the use of refrigeration.

Ambient air cooling, whereby external air is used to cool the crop, is one method used in stores to keep costs down. Ambient air does not need to be cooled therefore is around 75% cheaper than using refrigerated cooling.

Air mixing

If a mixing system is fitted, a minimum-desired duct air temperature can be regulated in relation to the crop temperature. Indeed, some more modern storage systems use this as their primary control parameter. On an ambient mixing system, in spells of cold weather, the inlet flap or louvre will be partially shut and the recirculation flap/louvre will partially open, causing the incoming air to blend with the warmer air coming back from the crop. This produces ventilation air that will not reduce the temperature too much (e.g. in a processing store) nor create too large a differential (typically <math><4^{\circ}\text{C}</math>) across the crop.

Ventilation rates

Bulk stores: In bulk stores, virtually all the air that leaves the fan will pass through the crop. Traditionally, the recommended ventilation rate for bulk stores in Great Britain has been $0.02 \text{ m}^3/\text{s/t}$, but, with quality parameters increasingly dependent on efficient drying,

there has been a move over to systems with higher rates of up to $0.04 \text{ m}^3/\text{s/t}$, where the airflow removes heat more rapidly, with less weight loss.

The introduction of affordable inverters (also known as variable-frequency drives or variable-speed drives) in the early 2000s enabled fan speeds to be adjusted and offered scope to lower rates once drying and/or pull-down is complete. This can provide significant savings in running costs; for example, reducing a fan to 80% of its full speed reduces the energy consumption by around 50%. It is also an effective way to circulate

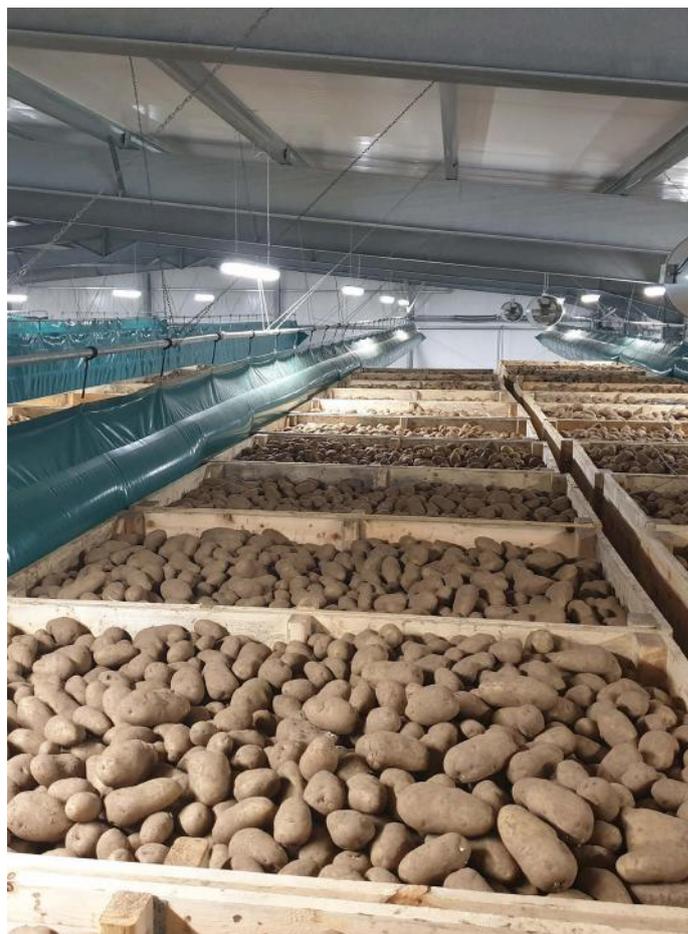
However, reducing airspeeds too much can be detrimental since there is a corresponding loss of pressure and this can adversely affect distribution if a system has been sized for a higher airflow, unless adjustments are made to rebalance the ductwork (this is what is done for slow-speed sprout suppressant application).

Fan running times and dehydration will also be increased and response times reduced at low speed.

Box stores: Airflow rates for box stores are, typically, designed to be $0.02 \text{ m}^3/\text{s/t}$, although a similar trend towards higher volumes has been observed in the past decade.

In space-ventilated 'overhead throw' stores, this airflow provides air movement around the boxes to dry and cool the crop. However, since the air is not forced through the boxes, heat transfer is partly by natural convection between boxes and the surrounding air and partly by the turbulent airflow created by the cool air jets passing over the top of the boxes and through their pallet apertures. This rate of airflow is primarily to aid distribution, rather than that required to remove the transferred heat, but overall efficiency of these stores is poor.

VENTILATION



Positive ventilation

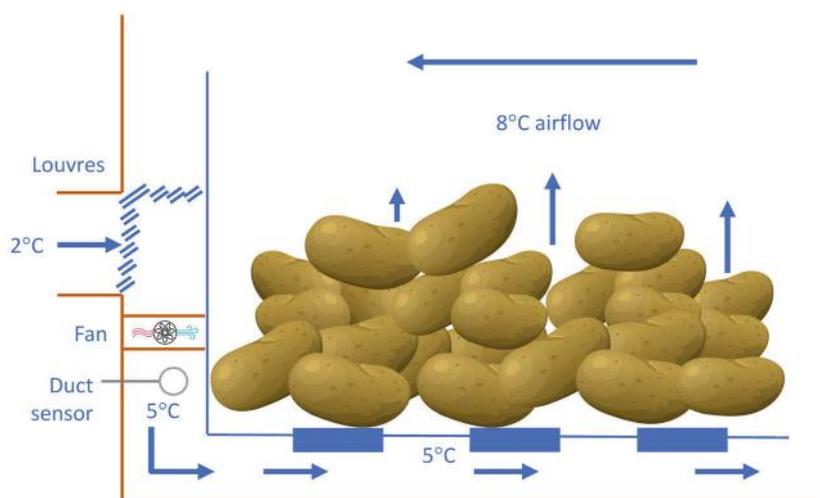
To achieve more rapid drying and cooling, systems of positive ventilation may be used that drive air through the potatoes. These are especially suited to densely packed, soil-contaminated potatoes and crops that are warm, wet or affected by disease. Positive ventilation is also a valuable tool for maintaining close temperature control (thereby limiting condensation risk) and application of sprout suppressants.

New storage systems are increasingly featuring positive ventilation systems, including those with greater capacity than conventional letterbox layouts, which are limited to a maximum of around 8–10 boxes from the duct. The lateral suction store layout is one such system and this is now available with automated sheeting rollers and inflatable sealing tubes to eliminate safety concerns with their fitment.

Cooling in 'overhead throw' stores

Since cooling in space-ventilated 'overhead throw' stores is from above the box and below, with the greatest airflow being over the top of the upper layer of boxes, space ventilation encourages an undesirable temperature profile within the box – cool at the surface and warm in the centre – which is liable to result in surface condensation when ventilation stops.

The reason this form of ventilation is so popular is that it is low in cost and utilises the otherwise unusable store headspace as a distribution 'duct'. The system works adequately

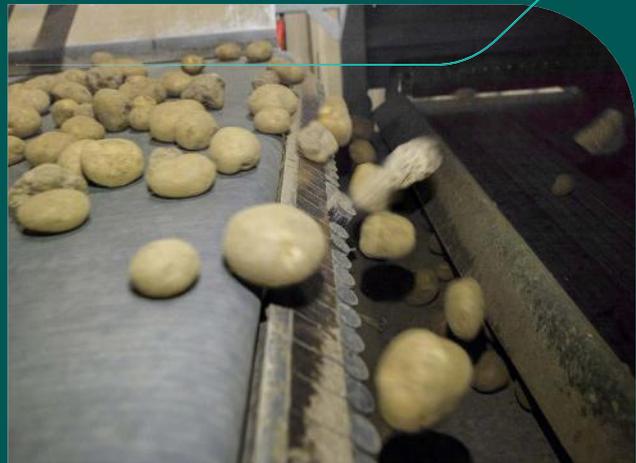


Air mixing, regulated by duct temperature, to permit use of very cold air for cooling.

but inefficiently. In principle, when cooling, the store becomes flooded with cool air. The air within the boxes is then warmer than the surrounding air, so the rate of convective ventilation increases. However, this process is much slower than in positive ventilation systems, so cooling takes longer.

For the system to work best, air distribution should be as uniform as possible over the whole area of the stack of boxes, but recent research has highlighted this is the primary deficiency of such stores, with as little as 15% of the air discharged from the fans reaching the far end of the store. A large component of the airflow short-circuits back to the fans through the sides and top of the boxes.

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Dew point assessment

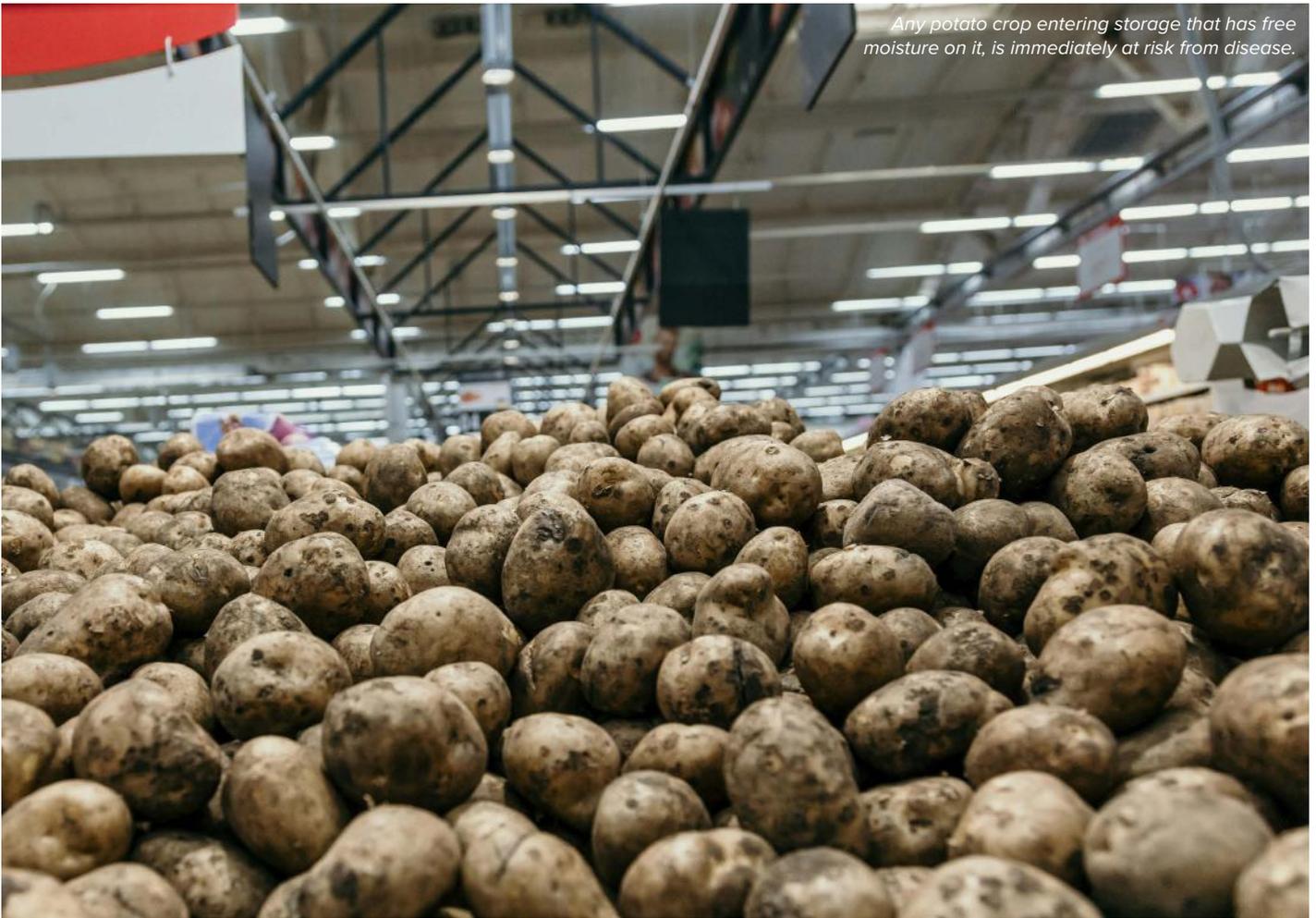
THE dew point is a measure of the actual amount of moisture in the air and is a specific temperature, not a percentage like relative humidity.

Maintaining the correct dew point in potato storage is crucial for preventing condensation. A relative humidity of

90-100% is recommended to minimise weight loss, but it is essential to keep the air temperature slightly warmer than the potato surface to prevent condensation from forming on the potatoes themselves.

The table below can be used to determine condensation risk.

Temperature	Relative humidity (%)													
	60	62	64	66	68	70	72	76	80	84	88	92	96	100
20	12.1	12.6	13.1	13.6	14.0	14.5	14.9	15.7	16.5	17.3	18.0	18.7	19.4	20.0
19	11.2	11.7	12.2	12.6	13.1	13.5	13.9	14.8	15.5	16.3	17.0	17.7	18.4	19.0
18	10.3	10.7	11.2	11.7	12.1	12.5	13.0	13.8	14.6	15.3	16.0	16.7	17.4	18.0
17	9.3	9.8	10.3	10.7	11.2	11.6	12.0	12.8	13.6	14.3	15.0	15.7	16.4	17.0
16	8.4	8.8	9.3	9.7	10.2	10.6	11.0	11.8	12.6	13.3	14.0	14.7	15.4	16.0
15	7.4	7.9	8.3	8.8	9.2	9.7	10.1	10.9	11.6	12.4	13.1	13.7	14.4	15.0
14	6.5	6.9	7.4	7.8	8.3	8.7	9.1	9.9	10.7	11.4	12.1	12.7	13.4	14.0
13	5.5	6.0	6.4	6.9	7.3	7.7	8.1	8.9	9.7	10.4	11.1	11.7	12.4	13.0
12	4.6	5.0	5.5	5.9	6.3	6.8	7.2	8.0	8.7	9.4	10.1	10.8	11.4	12.0
11	3.6	4.1	4.5	5.0	5.4	5.8	6.2	7.0	7.7	8.4	9.1	9.8	10.4	11.0
10	2.7	3.1	3.6	4.0	4.4	4.8	5.2	6.0	6.7	7.5	8.1	8.8	9.4	10.0
9	1.7	2.2	2.6	3.0	3.5	3.9	4.3	5.0	5.8	6.5	7.1	7.8	8.4	9.0
8	0.8	1.2	1.7	2.1	2.5	2.9	3.3	4.1	4.8	5.5	6.2	6.8	7.4	8.0
7	-0.1	0.3	0.7	1.1	1.5	2.0	2.3	3.1	3.8	4.5	5.2	5.8	6.4	7.0
6	-1.0	-0.6	-0.2	0.2	0.6	1.0	1.4	2.1	2.8	3.5	4.2	4.8	5.4	6.0
5	-1.8	-1.4	-1.0	-0.7	-0.3	0.0	0.4	1.2	1.9	2.5	3.2	3.8	4.4	5.0
4	-2.7	-2.3	-1.9	-1.5	-1.2	-0.8	-0.5	0.2	0.9	1.6	2.2	2.8	3.4	4.0
3	-3.5	-3.1	-2.7	-2.4	-2.0	-1.7	-1.3	-0.7	-0.1	0.6	1.2	1.8	2.4	3.0
2	-4.3	-4.0	-3.6	-3.2	-2.9	-2.5	-2.2	-1.5	-0.9	-0.3	0.2	0.8	1.4	2.0
1	-5.2	-4.8	-4.4	-4.1	-3.7	-3.4	-3.0	-2.4	-1.8	-1.2	-0.7	-0.1	0.4	1.0



Any potato crop entering storage that has free moisture on it, is immediately at risk from disease.

Drying, curing and pull-down

THE processes of drying, curing (wound healing) and pull down (temperature reduction) overlap and interact.

Whilst they are separate elements of the store management process, it is important to have an appreciation of how they affect each other to make sure the crop is kept in the best possible condition.

Drying

Drying is perhaps the most critical phase of store management as any crop entering storage that has free moisture on it is immediately at risk from disease.

Removal of any free moisture has to be the priority and this is best achieved using ventilation from day one. Positive ventilation provides the most effective drying.

Positive ventilation is where all of the air delivered has to pass through the box or pile of potatoes. In bulk stores, this is achieved by delivering the air under the pile. In box stores, it requires a specifically-designed system. Letterbox or lateral suction stores are examples of positively-ventilated box storage systems.

Most overhead throw ventilated box stores are non-positive, even if they are fitted with plenums or suction walls.

Airflow rates for drying should always be the maximum available. Batch systems can be well suited to drying, as air can be concentrated on a small section of damage at a time.

Typical airflow rates for effective drying would range from 0.02 - 0.05m³/s/t in bulk stores. Box stores need up to 0.08 m³/s/t to allow for air leakage.

Curing

Curing is an important element of potato storage best practice as the mechanical handling involved in harvesting the crop and getting it into a store often results in some level of damage and/or bruising. This needs to be cured to minimise any long-term impact on keeping quality. Curing is an important management tool for minimising weight loss and disease.

If potato tissue is damaged, this can allow fungi and bacteria to infect the tuber. Fortunately, the potato has a robust natural defence mechanism to cure any damage. It quickly lays down a thin cork-like layer of suberin between and below damaged cells to provide an initial barrier to infection and moisture loss. The rate of this wound healing is temperature and time dependent.

DRYING, CURING AND PULL-DOWN

The curing process is faster in recently harvested crops compared with physiologically old crops that may have been held in store for some time.

In addition to keeping out infection, the curing process helps to minimise moisture loss. Damaged tissue can lose water very quickly, as much as 100 times faster than undamaged skin.

Normally, the curing process is one that takes place concurrently with the drying and cooling phases after harvest and no specific management input is needed. The exception to this is in very cold/late harvest periods. If the crop is too cold, the curing process is very slow and this can expose tubers to diseases such as skin spot and gangrene. A curing period of seven to 10 days when the temperature is allowed to rise can offset this risk.

'Dry curing', where crops are ventilated with suitable ambient air immediately they enter the store, allows drying, wound healing and heat removal to take place concurrently. The aim when using this technique is to remove all surface moisture from the crop and then to keep it dry. It is important to stress this last point. Use of air that is too warm can cause rewetting from condensation and the drying process has to be started again.

If conditions are not suitable for drying, it is important to maintain air movement in the store to prevent temperature gradients developing. Do this by setting up regular recirculation using automated control. This can be especially useful at night when the store is closed.

Tuber temperature (°C)	Initial suberisation (days)	Periderm complete (days)
<5	7-14	21-42
10	4	7-14
20	1-2	3-6

Pull-down

Temperature reduction can usually start as soon as the drying process is complete, assuming there was sufficient heat in the crop to complete curing.

Rapid cooling may be necessary in instances where there is a lot of field heat to remove (eg in salad crops) or where there is a specific risk of disease development (eg black dot or bacterial soft rot).

Take care, when cooling quickly, not to create large temperature gradients which might trigger condensation, especially if the fans are turned off.

Generally, maximum pull down rates will be limited to around 0.5°C/day in most stores unless positive ventilation is available.

For some markets, a lower rate of temperature reduction (0.2-0.3°C/day) will be more appropriate, notably in crops being held for chipping and/or processing.



Box stores need up to 0.08 m³/s/t to allow for air leakage.



Condensation control

CONDENSATION is one of the biggest risks to the stability of the potato crop in storage.

In a sealed building, potatoes can very quickly create an environment with a high relative humidity (RH) of 90% or more. This is largely driven by the evaporation of moisture from the tuber skin.

At such high RH, condensation can form on the crop or the building structure if the surface is only marginally colder (sometimes less than 1°C) than the air.

Why does condensation form?

Basically, warm air can carry more moisture vapour and cool air. The RH value is a way of expressing how much moisture is in a given volume of air in relation to its maximum capacity. As air approaches saturation, there is little room for variation and the dewpoint, when free moisture starts to form, is easily reached.

Condensation on the crop will occur if

- air surrounding the potatoes is warmer than the crop
- potatoes' surface temperature is below the dew point of the air

As a very general rule, a temperature difference of 4°C or more between the warm air and the cooler crop will result in condensation. But, in some situations, this difference may only need to be as little as 1°C for wetting to occur.

It's possible to control condensation by minimising temperature differentials. At harvest, you should try to keep the store close to the temperature of the potatoes being loaded.

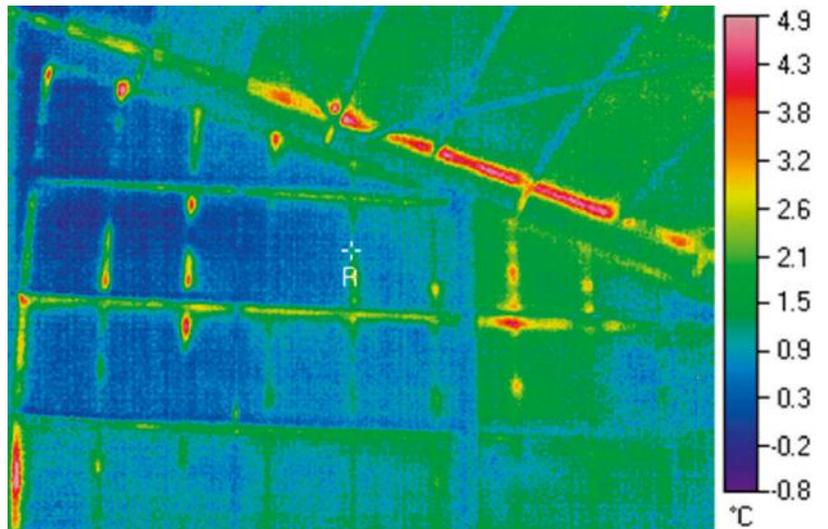
You'll need to keep air moving to reduce the risk of differentials becoming established and of moisture fall out.

In bulk stores, place sensors 100mm and 300mm down in the pile. Try to keep these readings similar. Use roof space heating to manage this.

Try to limit warmer air coming into contact with the crop. Seal gaps in the structure and keep doors closed. Only ventilate with air warmer than the potatoes if the crop temperature is above the air's dewpoint.

CONDENSATION CONTROL

Spray foam insulation is an effective solution for potato stores owing to its ability to create an airtight and insulated environment, which helps maintain consistent temperatures and control condensation.



Thermal imaging is a good tool for identifying weaknesses in insulation. Eaves lines - as shown here - are common sites of air leakage that result in condensation.

Structural condensation

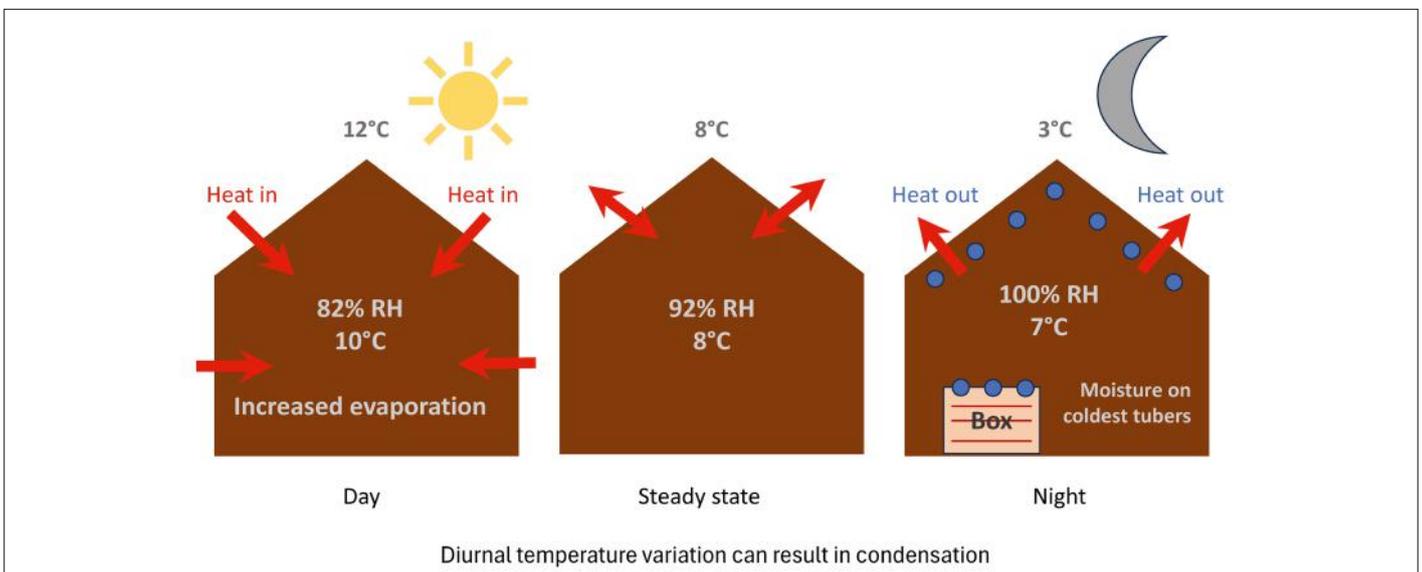
Any condensation forming on the building structure can often lead to problems.

Ensure that insulation levels are at least 75mm thick for refrigerated stores and 50mm for ambient cooled stores. Most new stores have 100-120mm.

If condensation forms on the underside of the store roof, it can easily run down and trip onto the potatoes starting rotting or localised sprouting. Similarly condensation on the walls in a bulk store may run behind the stack.

- Structural condensation can occur if
- the store insulation is failing or insufficient
 - air movement across the roof space is inadequate
 - cold weather or day/night variation results in heat loss from the store roof
 - internal store air is saturated (100%RH)

Sometimes condensation can form within the roof structure, leading to dripping from joints or sagging of roof insulation. You should seek specialist assistance to get this rectified.



Refrigeration

POTATO storage under refrigerated conditions provides potential for close environmental control around the crop, irrespective of the ambient conditions.

Increasingly, as store managers look to achieve closer regulation of the storage environment, refrigeration has a bigger part to play - albeit at a cost.

Fridges have been used for many years as the principal means of cooling for fresh and seed potato stores but it is also becoming more important as part of processing storage capability to regulate temperatures during warm autumn loading and for long-term storage until June/July.

Long-term storage can account for up to 100kWh of energy use per tonne so it is important to ensure these systems are running as efficiently as possible to preserve margins.

A standard 'DX' fridge system consists of two heat exchangers: The evaporator or cooling coils inside the store and the condenser outside.

Heat is transferred to the refrigerant under pressure and released outside the store via the condenser coil.

Older condensers have multiple fans controlled on pressure switches to dissipate heat whereas more modern units generally have fewer, larger, variable speed EC fans for more efficient dispersal of heat.

In recent years, there has been a trend towards use of secondary refrigeration systems in potato stores, which use glycol to transfer heat from the store to the primary refrigerator.

Compliance legislation governing the use of refrigerant gases has been in place for many years, but continues to be updated to reduce their environmental impact. Gases such as R22 and R404A (banned from use from 2020 or earlier) need to be replaced by more environmentally-friendly options with a lower global warming potential (GWP). If used for retrospective replacement, they are referred to as drop-in refrigerants; examples include the blends R407F, R407A, R448A, R449A and R452A.



High-capacity fridge system.



Reversed fridge coil to optimise air distribution.

REFRIGERATION

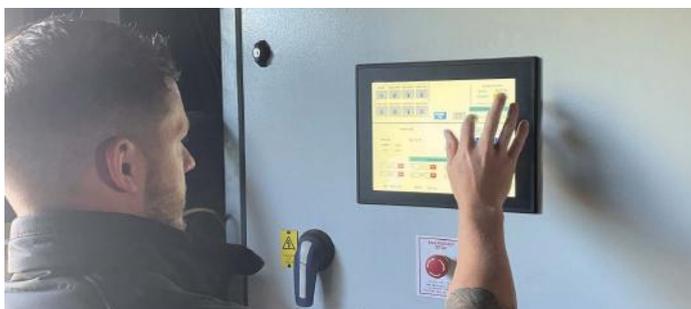
High performance, environmentally friendly refrigerants such as propane (R290) are now being used in some installations.

All fridge systems require regular professional servicing by an accredited engineer who can also advise on the system's ongoing compliance.

Good practice checks that can be carried out when a fridge system is used include:

- Compressor crank case oil heating should be switched on 24 hours before starting
- Condenser coils outside should be free of leaves and debris
- Refrigerant should be dry and clear of air bubbles in the sight glass
- Compressor is on when the recirculation fans are operating
- Monitor high/low pressure controls which can trip the compressor off even though the fans may still run

Control of refrigeration systems is increasingly sophisticated, with the advent of systems regulating use in response to the availability of renewable energy now becoming a more common feature. Defrost 'on demand' is another efficiency measure which helps reduce unnecessary addition of heat into the store.



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By supplementing the moisture content of the air through humidification, there is scope to increase its RH and reduce moisture loss from the crop.

Humidity control

POTATOES have a very high moisture content (75-80% water typically) and continually lose water to the storage environment through evaporation.

This loss can be accelerated by ventilation because, as air moves through the crop, it evaporates moisture more quickly. The air also picks up heat as it cools the crop. This lowers its RH and increases its drying capacity.

At about 4°C, it is not until humidity levels are at 98% RH that they reach an equilibrium with the surrounding air, where they neither lose nor gain moisture. This is very close to saturation, which essentially means that, in practice, all potatoes suffer some weight loss in storage.

Ventilation increases weight loss as the air evaporates moisture from the skin. If the skin is breached, owing to damage or not being fully set, more moisture loss will result.

Dehydration risks can be minimised by ensuring good skin set and optimising interventions (fan and fridge use) to the bare minimum needed to maintain the storage environment required.

Humidification

Adding moisture into the store air, to limit dehydration, is known as humidification. A number of differing systems are available.

It is not a particularly common practice in the UK but, where it is used, it would most probably be targeted at ambient processing stores being held at temperatures above 6°C.

Humidification is a process undertaken in some stores to add moisture back into the ventilating air so its humidity is raised and it dehydrates less. This can be achieved a) by directly injecting water into the airstream using atomisers or spinning discs or b) by passing high volumes of air through a wet, perforated cellular membrane. In either case, humidification will only be partial and care needs to be taken to avoid free water deposition onto the crop either directly or by increasing the risk of condensation.

A significant benefit of humidifying the air is its capacity for evaporative cooling. This is because of the latent heat of evaporation. It means that humidified systems can operate at very close air/crop differentials as the differential is widened owing to the cooling effect of water evaporation. This is known as adiabatic cooling.

Humidification should only be used in stores which are very well sealed and which have a close degree of temperature control (range <0. 5°C). This is because, as humidity approaches saturation (100%), it means there is less tolerance for temperature variation before condensation occurs.

HUMIDITY CONTROL

Dehydration is minimised by

- a) ensuring skins are fully 'set' before harvest
- b) limiting ventilation to that needed to manage the storage condition of the crop

Fridges with large evaporator coils also help to limit the dehydration effect of the cooling system, as the coil can be run at a temperature closer to that of the crop (smaller TD).

Unnecessary recirculation or defrost events increase weight loss for no gain, so it is important to control ventilation automatically wherever possible.

Weight loss

Weight loss (sometimes referred to as 'shrink') and the risk of compression bruising in storage can be mitigated through the use of humidification but cannot be eliminated. It is important to monitor dehydration as undue softening could make the crop unsaleable. Typically, weight loss could vary from 3% up to 10% or higher depending on multiple factors, including tuber condition and temperature, in long term storage. It will often be highest in the first month or two of the storage period. Damage, disease and poor skin set contribute to a heightened risk of weight loss.

“A significant benefit of humidifying the air is its capacity for evaporative cooling.”



Humidified systems can operate at very close air/crop differentials.



Dehydration risks can be minimised by ensuring good skin set.

ENERGY MONITORING

Some companies, including Greenvale and Albert Bartlett, have installed wind turbines. The technology can be combined with other smart systems to manage and optimise energy use.



Energy monitoring can range from the regular, organised reading and manual recording of utility meters on site, to the use of sophisticated data-logging equipment.

Energy monitoring

ENERGY costs are ever-increasing, with higher wholesale energy costs resulting from global events and increased network and policy costs. Added to this is an increasing focus on environmental issues and the carbon footprint of storage.

Understanding energy use and exploring energy-saving options such as solar panels and wind turbines are now high priorities for those running potato storage facilities.

During storage, cooling is the biggest consumer of energy, regardless of whether ambient or refrigerated air is being used to cool the crop.

To effectively manage energy consumption, monitoring is key. This is a relatively cheap exercise to undertake and allows managers to identify high-energy-use equipment and times, see where problems may be occurring and make rational decisions on investment in energy-saving equipment.

ELECTRICITY USAGE GUIDE: How efficient is your store?

Usage	Fresh	Process
Low	< 0.30	< 0.10
Medium	0.30 – 0.50	0.10 – 0.50
High	> 0.50	> 0.25
KWh/tonne/day		

ENERGY MONITORING



Solar energy can be used in potato stores to power refrigeration, ventilation, and other machinery.

Energy monitoring can range from the regular, organised reading and manual recording of utility meters on site, to the use of sophisticated data-logging equipment. It can be applied to whole sites or, by sub-metering, to individual buildings and pieces of equipment. Store-specific metering is recommended.

If it isn't practical to have separate store meters, it's possible to estimate energy use per store via the running times of fans and fridges. For each store, total the power rating in kW or HP stamped on the electric motors that run when the ambient air cooling is operating and when the refrigeration is running.

In today's economic climate, price comparison is more relevant than ever. Those running stores could well save money by comparing different electricity suppliers' costs, and looking at changing their contracts or tariffs.

If you need assistance with this, specialist energy brokers can compare prices and negotiate contracts on your behalf. Acting as intermediaries between businesses and energy suppliers, they can often provide access to exclusive rates or tariffs, simplify the process and save you time on initial negotiation and renewals.

Building improvements

Leakage of warm ambient air into stores, through gaps in the structure, joints and doors is a primary cause of condensation. It also leads to excessive cooling fan or refrigeration running costs.

Major air-leakage points are obvious, as daylight can be seen through the gaps from inside a dark store.

Other leaks, such as gaps between composite panels, may only be identified by detecting draughts on a windy day or by use of equipment such as a thermal-imaging camera.

Simple solutions, such as fitting new door seals, can often help minimise air leakage and, consequently, reduce energy use.

Variable frequency drives

The energy efficiency of ventilation and fridge systems, such as condensers, fans and compressors, can be improved through the use of variable frequency drives (VFDs, also known as inverters) which changed the frequency and voltage of power supplied to AC electric motors. This allows the equipment's performance to be adjusted to the store's needs rather than adopting a 'one-size-fits-all' approach. Major advantages of this are that the use of VFDs lowers start-up loads and, where appropriate, can disproportionately reduce running costs. For example, running a fan at 80% of full speed lowers costs by almost 50%.

It's worth highlighting that a fan will often consume energy equivalent to its capital cost within just one season so, when upgrading equipment, the extra cost of new technology or a more efficient motor needs to be offset against the delivery of energy savings. →

Capital costs

UNDERSTANDING the costs involved in storing potatoes is key to successful management, as it is with any type of business, and it's easy to overlook some of the less obvious ones.

Knowing what a specific target market requires, and the specifications in which the crop should be delivered is essential to the initial undertaking (see 'Market Requirements' overleaf).

During the storage period, you should carry out routine steps to ensure this specification can still be achieved, including regular sampling and quality assessment. This will help to avoid uncertainty or any unwanted surprises if the crop's condition changes in store.

There are two types of potato storage costs: Fixed and variable. Fixed costs are those of the storage building itself, while variable costs are incurred by using the store (i.e. running costs).

Examples of fixed costs are:

- Depreciation to cover capital costs, including: Storage building; associated concrete to service the store; dedicated power supplies; ventilation/fridge equipment, boxes
- Finance costs to cover borrowing (or loss of interest) on the money used for capital
- Building maintenance and repairs
- Building insurance

Typical depreciation periods would be 20 to 30 years for buildings; 10 to 15 years for fans and refrigeration systems and eight to 10 years for wooden boxes.

Examples of variable costs are:

- Electricity
- Loading and unloading
- Store cleaning/hygiene
- Chemical treatments
- Equipment maintenance and repairs
- Crop insurance
- Crop monitoring and management
- Storage losses, e.g. weight loss; deterioration of quality in store
- Opportunity cost for delayed payment (i.e. payment after storage, compared with at harvest)

Studies have shown that there is a wide variation between electricity usage in different stores – in the past this has been shown to be as much as 300% between stores of the same type. Obviously this represents a big difference in cost (range 0.09 kWh/tonne/day to 0.27 kWh/t/d).

Having store-specific metering in place is essential in order to obtain accurate running costs. Current transformer (CT) links onto most supplies can be used to install meters. It's inexpensive to do.



Store-specific metering is recommended.

Good control is essential in providing optimal storage conditions at the lowest energy cost. Compared with many capital investment options, control is generally quite cheap to integrate into an existing store. The ability to regulate refrigeration use to coincide with a cheaper night tariff can make significant cost savings.

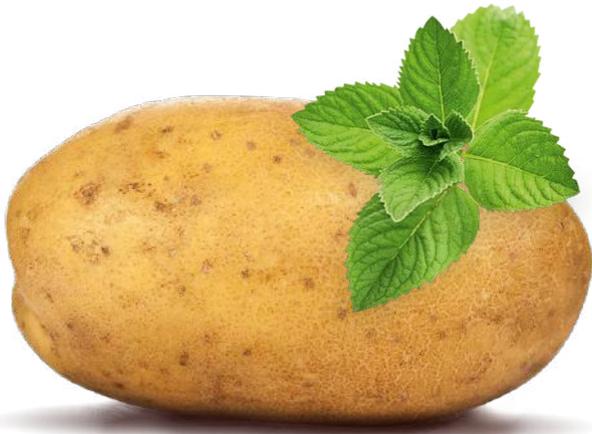
Web-based forecasting systems are increasingly available on new store controllers to anticipate the weather and delay cooling until cool ambient air is available.

Record-keeping

Good records must be maintained if you are looking to improve storage efficiency. Without them, it is difficult to assess whether changes are real and worthwhile or simply a facet of the many variables that relate to storage use. For example, a simple change in storage duration of a week between seasons could easily hide a 2% difference in energy consumption.

If major decisions around the use of a store are contemplated, you should consider engaging a specialist energy-auditing service, which will highlight where true energy savings can be made. These services typically involve analysing energy bills, performing a physical inspection of equipment and systems like heating, ventilation, air conditioning and lighting. It will provide a detailed report with actionable recommendations to reduce energy consumption, lower utility bills, meet compliance requirements, and improve a company's sustainability performance.

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Sprout suppression

POTATOES usually enter stores when they are dormant and sprout free, even under conditions favourable for growth. Their status is determined by variety and season.

After dormancy has broken, the rate of sprout growth is primarily determined by temperature. Lowering storage temperature is therefore an effective way of controlling sprouting first by prolonging dormancy and then slowing growth.

To suppress sprouting entirely by means of temperature, potatoes need to be kept constantly below 3°C. Holding crops for the fresh market at this level will induce low temperature sweetening which will affect taste, texture and colour on frying/roasting.

Storage at warmer temperature, which is best practice for processing crops, will require the use of sprout suppressants for all but the shortest storage periods.

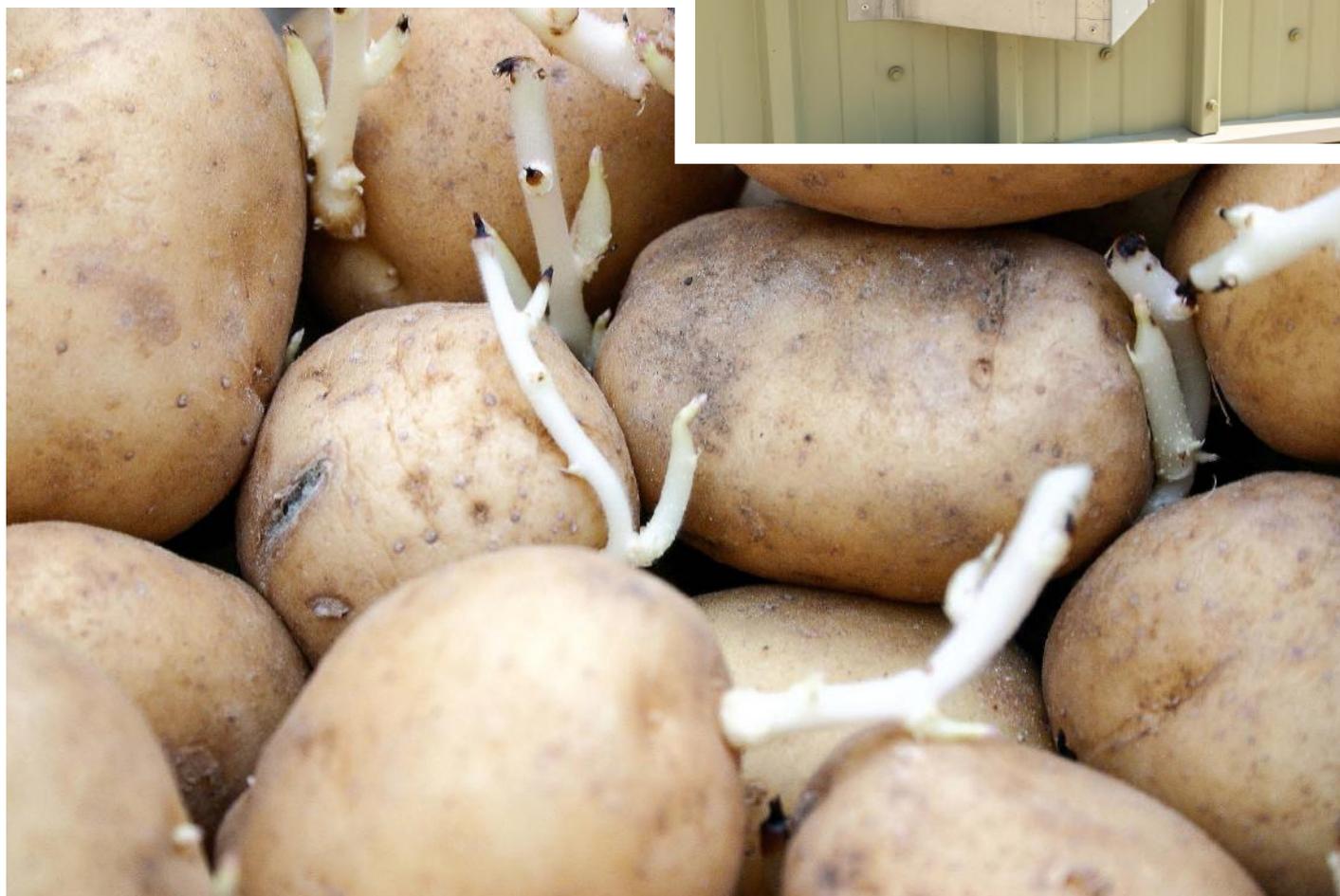
Chemical treatments with the active substances 1-4 dimethylnaphthalene (DMN), ethylene, maleic hydrazide, orange oil or spearmint oil are all options for sprout suppression in stored potatoes in the UK. Always consult your market before selecting a sprout control product.

Minimisation strategies

Take steps to avoid any unnecessary use of sprout suppressant. Consider doing the following:

- Selecting varieties with long dormancy and low temperature tolerance as this will reduce the need for suppression.
- Plan store loading ahead so that you can segregate storage by dormancy. Varieties with contrasting dormancy characteristics are best held in separate stores to avoid unnecessary treatments.
- Consider use of combination treatments, especially if this includes a product, such as maleic hydrazide, that provides residual control between applications.

Install specific ports for sprout suppressant application.



Severe sprouting in potatoes occurs when they are stored in warm conditions. To suppress sprouting entirely by means of temperature, potatoes need to be kept constantly below 3°C.

SPROUT SUPPRESSION



Ethylene is applied using the equipment shown here.

Application

With the exception of maleic hydrazide, which is applied to the growing crop in the field in late summer, all of the suppressants can be applied once the crop is in store.

Care should be taken to adhere to label requirements in all cases.

Ethylene is applied using specialist equipment specific to the product selected. Be aware that, because it is a plant hormone,

responses vary significantly between varieties. Its introduction to stores needs to be gradual to avoid any adverse reaction in the crop; always consult your ethylene supplier. Ethylene has been shown to interact with CO₂ and negatively influence fry colour in processing varieties; suppliers may suggest a threshold below which CO₂ should be kept in stores where ethylene is used.

The remaining products, 1-4 DMN, orange oil and spearmint oil, are all applied as thermal fogs. They must be applied when the crop is dry. Failure to do so will result in scorch. Best practice is to engage the fans, without cooling, for 24 hours before application to ensure temperatures are even and any residual moisture is removed.

The use of fans at moderate speed (usually inverter-controlled to provide an air speed of 3 - 5 m/s) would normally accompany a hot-fog application. Take special care in cold weather when the viscosity of the active substance can be very low.

After application of a fogged product in store, the building will need to be kept closed for a minimum of 24 hours to allow the suppressant to distribute, using a recirculating fan if necessary. Even distribution of volatile chemical treatments is essential for optimum efficacy.

Always consult a BASIS-qualified advisor/contractor before making an application of sprout suppressant. Remember also to adhere to any specified harvest interval (ie the time between the last treatment and sale).

Residues

Crops held in stores treated with sprout suppressant may be subject to sampling to ensure that maximum residue levels are being complied with. This could include sampling for active substances that are no longer approved, eg chlorpropham.

The first part of your potato sprout control programme



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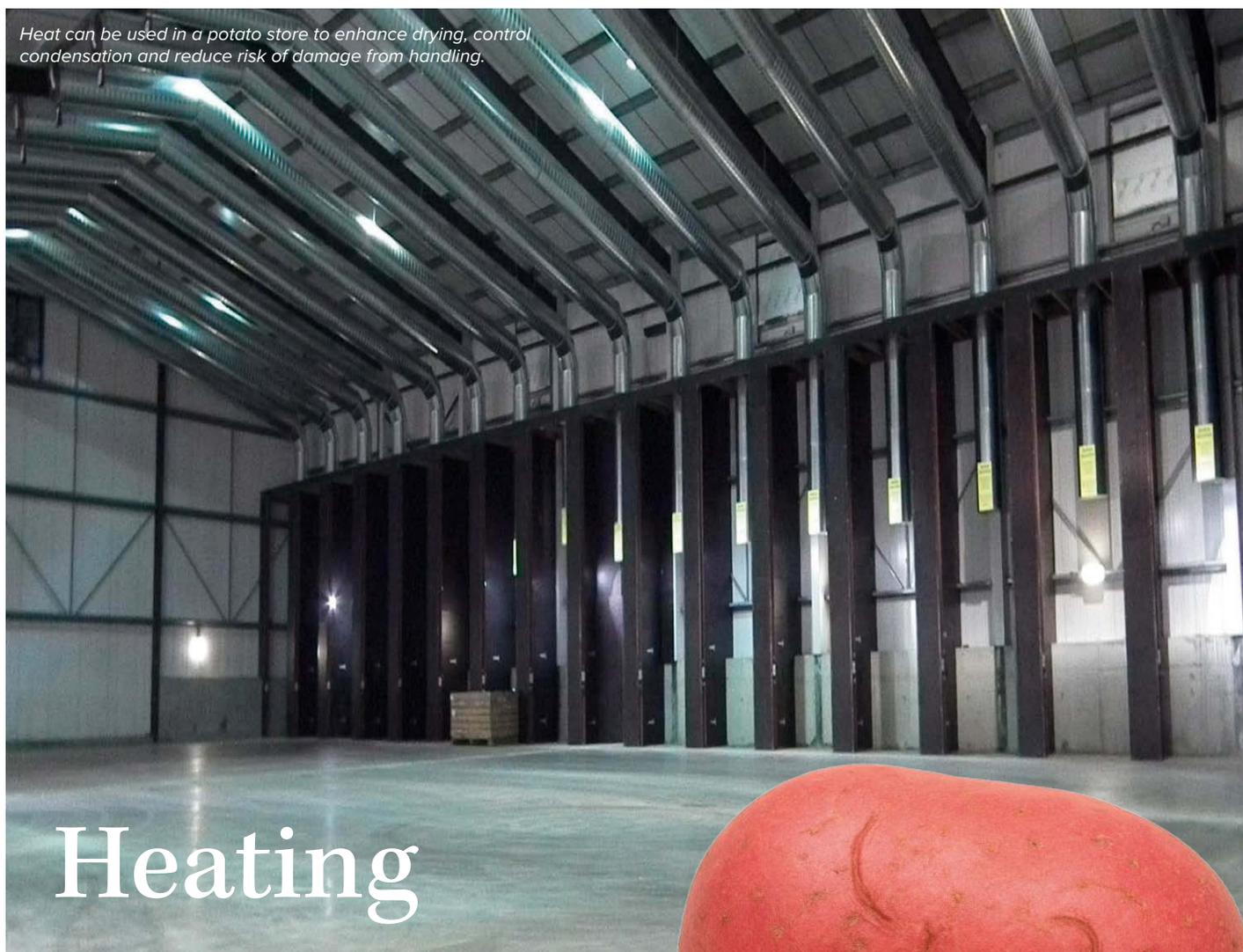
Argos

Effective and powerful sprout inhibitor for stored potatoes

Control and prevent sprouting
in store, with no effect on taste,
odour, or fry colour.

Mapp No. 19799. ARGOS contains 843.2g/L (99.9% w/w) orange oil as a cold fogging concentrate (KN) or as a hot fogging concentrate (HN) formulation. For use as a sprout inhibitor on stored potatoes (please see label for details). Use plant protection products safely. Always read the label and product information before use. Pay attention to risk indications and follow the safety precautions on the label. ARGOS is a registered trademark of UPL © UPL Europe Ltd 2025.

Heat can be used in a potato store to enhance drying, control condensation and reduce risk of damage from handling.



Heating

HEAT can be used in a potato store for the following:

- Enhancement of drying
- Condensation control/frost protection
- Warming to reduce the risk of damage when handling

Drying

Adding heat to ambient air to enhance its drying capacity can be done in cold and wet conditions. This allows the wet crop to be dried much more quickly than would otherwise be possible. The technique requires careful regulation to ensure that any combustion by-products are flushed from the store, so as not to place a stress on the crop.

Roof space heating

The use of heaters in the roof space of processing stores is a means of controlling structural condensation and helps to avoid subsurface wetting if the air space becomes cold.

In extremely cold weather, adding heat can also offer some protection against frost damage.

Warming to reduce the risk of damage

Potatoes handled at temperatures below 8°C are more susceptible to impact damage or bruising. It is therefore recommended that crops held below 6°C are warmed before handling/grading.

If crops are warmed with air that is too hot, tuber skins will rapidly lose moisture, making them taut and prone to tearing



Thumbnail cracking.

when handled. This can cause thumbnail cracking (see picture). Allow 24 hours' recovery time if a risk of thumbnail cracking is suspected.

To warm crops to 10°C, the warming air should also be at 10°C. The rate of warming is dependent on the flow of air between the tubers. If boxes of potatoes at 3°C are placed in a grading 10°C, natural convective ventilation will warm them up in about four days. However, if the air is forced through the boxes, the rate of warming can be increased in line with the rate of airflow. At a heightened air delivery rate of 0.8 m³/s/t, warming a crop by 6°C will take about 12 hours. Care needs to be taken to ensure that the air is dry enough not to create condensation as rewetting will require the crop to be dried again.

To accelerate warming of multiple stocks, it is possible to use a forced volume (blowing) or extraction (suction) system that provides continual ventilation of each lane, regulating air volume in proportion to the temperature difference between the stock and the store.



The high humidity environment of a potato store makes it particularly prone to condensation and, where this is combined with automated equipment, it can create a heightened risk of electric shock.

Risk assessment

COMPLETION of a risk assessment is the easiest way to consider health and safety in a potato store.

Specialist help is available to advise on the process in detail, but further guidance can be found at hse.gov.uk/risk.

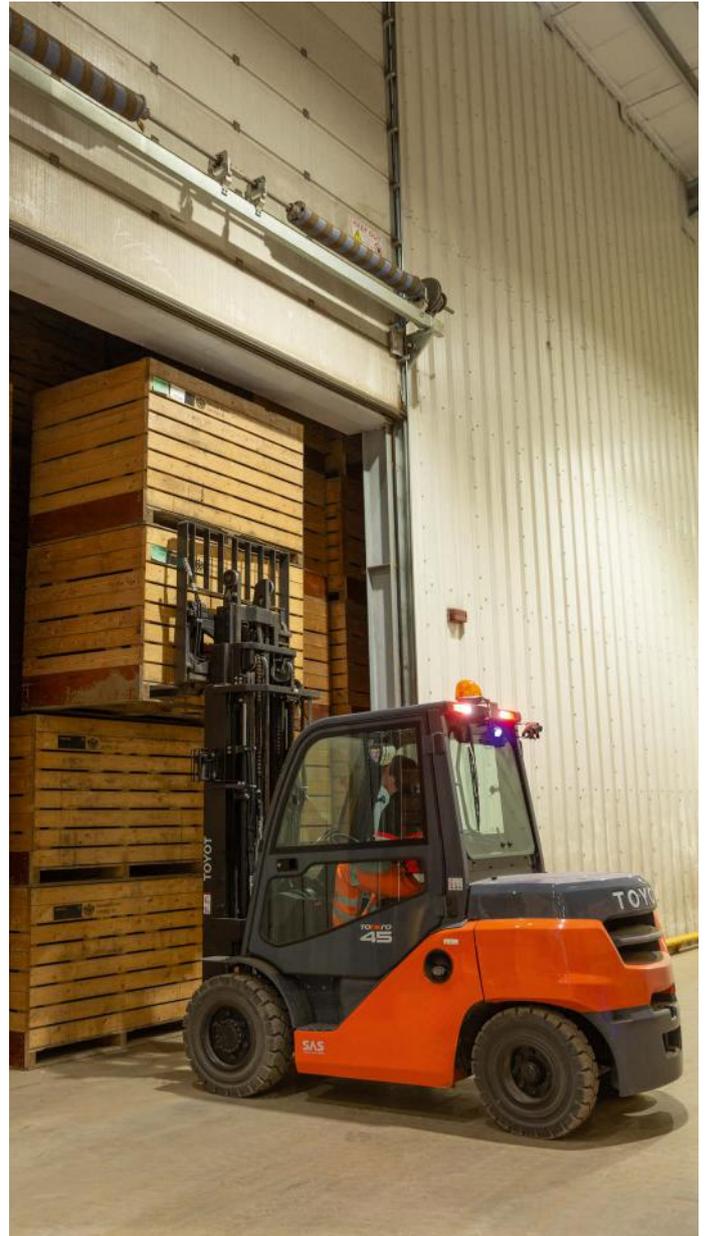
Issues frequently encountered in potato stores requiring risk assessment include:

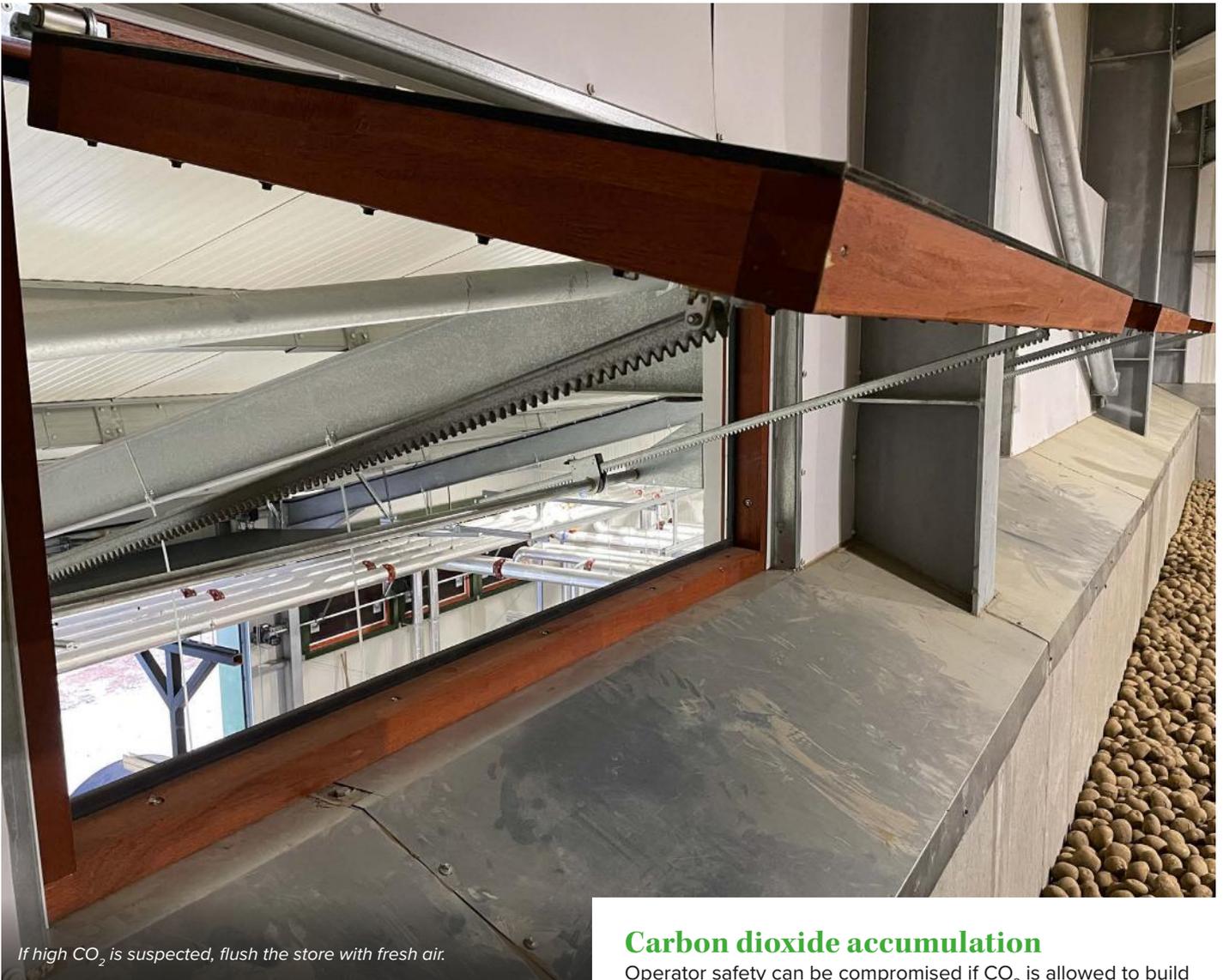
- Lone working
- Electrical shock
- Chemical use
- Pest control
- Working at height
- Carbon dioxide build-up
- Box stacking
- Exposure to dust
- Poor lighting
- Trips and slips
- Pedestrian / forklift conflicts
- Enclosed spaces
- Infrastructure degradation

Lone working

This is a major risk in potato stores as many buildings are remotely located and have poor communication capability. If working alone, don't simply rely on a mobile phone as it may not work.

Always tell someone where you are going and how long you expect to be there. Check in and out with them. Alternatively, consider using a tracking tag that leaves a historical footprint of your movement around a site or locality.





Carbon dioxide accumulation

Operator safety can be compromised if CO₂ is allowed to build up in a store. Common signs of high carbon dioxide levels include breathlessness and dizziness. If high CO₂ is suspected, flush the store with fresh air. The air can be changed in most stores within 30 minutes.

Chemical use

Chemicals may be used regularly in store for controlling sprouting, pests or diseases. Specific legislation exists to control their use. Any use of pesticides within a potato store must adhere to the label and be approved by a BASIS-qualified advisor.

Infrastructure degradation

Many potato stores, especially older ones, are built from materials, such as timber or steel, that degrades over time. This is especially the case in high moisture environments. Where these structures are relied upon for access (eg elevated walkways) or protection (eg handrails), it is important to check their integrity from time to time to ensure they remain safe and fit for purpose.

Electrical shock risk

The high humidity environment of a potato store makes it particularly prone to condensation and, where this is combined with automated equipment, it can create a heightened risk of electric shock. Fit good breaker systems that trip the supply off to protect operators.

Many store managers work alone, placing them at risk in the event of an accident. It is important therefore to have procedures in place for those who are working in isolated locations.

Poor signal reception in storage buildings means that mobile phones are generally unreliable so, if working alone, consider these alternatives:

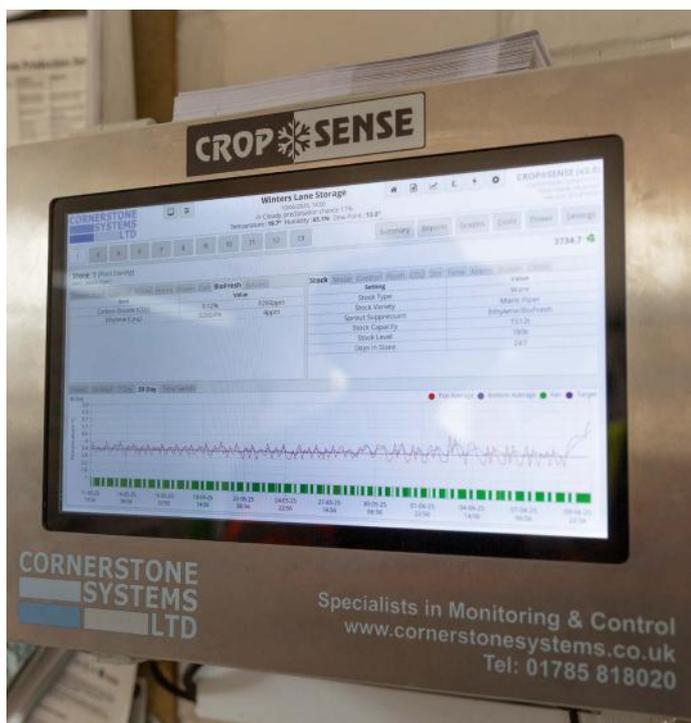
- Tell someone where you are going and how long you will be there
- Try to log in and log out of remote sites
- Place signs on doors to alert others that someone is in the store
- Use a tag system or tracking device.

Working at height

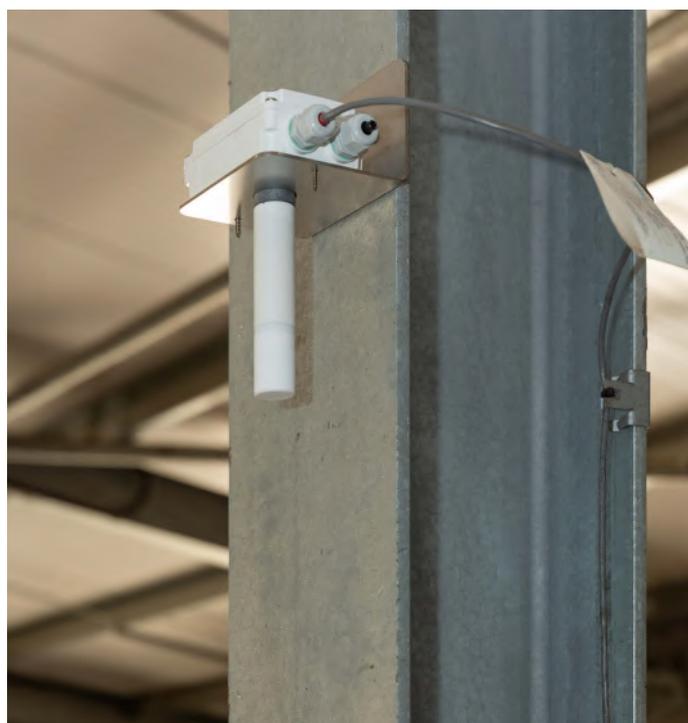
The Working at Height Regulations came into effect in 2005. Under this legislation, potato storage is not considered a short-term activity. As a result, the use of long ladders to access the top of stores for routine inspection was deemed illegal.

If inspection of the top of potatoes is required, an alternative means of access must be provided. Many plenums now have stairs built within them or an external stairway to the top. Alternatively, mobile electric work platforms (MEWPs) and fork lift access 'cages' may be used.

When on top of the stack, it is also necessary to install a physical barrier to alert operatives to any gaps between boxes or proximity to the edge.



Computerised store monitoring system.



Carbon dioxide sensor

Store monitoring and QC

KEEPING good records is a key aspect of potato store management. These can inform the decision-making across multiple seasons and also offer an important backup for quality assurance, especially if an unforeseen problem occurs.

It is recommended that a store diary is kept to record general store management information and key dates in relation to all stocks held in store. A good record/plan of location of stocks should also be kept. There is of course the option to do this in a manual or electronic manner and, if electronic, to take advantage of some of the innovative, storage-specific software now available.

Store monitoring

Store temperatures and controls should be checked, ideally, every day. Take note not only of the temperatures but also of the run times of the control equipment as this can be very instructive.

Remote monitoring systems offer the opportunity to check on stores without having to travel to site every day, but a weekly site check is recommended. In addition, routine sampling to verify crop quality in relation to specific market requirements should take place. Storage is expensive and crop condition can change rapidly, so it is best to try to avoid any unwanted surprises!

Do not take the output from computer controllers as categoric; systems are often unlikely to interface with hardware well enough to detect a local loss of power or an isolating switch a service engineer has forgotten to reset.

Inspection

Carry out regular inspections of stores, even if they are located remotely. There is no substitute for going into a potato store to determine if it is keeping well.

Have a kit of equipment available to enable this to be done, comprising:

- High visibility thermal jacket
- Bump cap
- Gloves
- Safety boots or shoes
- Torches: head torch and back-up
- Carbon dioxide monitor/alarm
- Hand held thermometer
- Hand held anemometer

In addition, if appropriate, there should be a process in place for lone working that forms part of the health & safety risk assessment.

Servicing

Regular servicing of equipment helps to reduce the risk of breakdowns which may badly compromise crop quality if store control is lost.

Annual checks and servicing should take place in the summer months, ready for the new season.

Verification of temperature recording equipment against a good reliable handheld reference thermometer should also be carried out.

Keep service records in a safe place as it is important to be able to demonstrate due diligence in the management of the store for quality assurance.

Market factors

STORE operators should have a good understanding of the different market segments they serve, be that fresh/table, processing or seed, as each has unique quality specifications in terms of tuber size, shape and specific gravity, driven by consumer preferences.

The following considerations should be made taking into account the demands of each market, principles of field management, pre-holding and holding in store, and eventual unloading.

Sector demands

PROCESSING:

- Uniform and acceptable fry colour
- Low levels of rot and skin spot (peeling waste)
- Freedom from sprouting
- Dry matter appropriate for market
- Controlled use of sprout suppression

FRESH/PRE-PACK:

- Bright, shiny skins
- Low levels of scuffing/damage
- Low levels of blemish disease
- Freedom from sprouting
- Minimal residues

SEED:

- Specific size requirements
- Low levels of disease
- Freedom from sprouting

Field management for storage

PROCESSING:

- Plan to harvest mature crops before soil temperatures dip below 8°C
- Agronomy (e.g. canopy management, seed selection, planting density and nutrition) to contribute to achieving size and maturity that permits long-term storage

FRESH/PRE-PACK:

- Plan to minimise time crop is in field to avoid disease development
- Bearing above in mind, agronomy to focus on achieving size and skin set that allows lifting to minimise damage
- Harvest when dry
- Minimise damage and bruising

SEED:

- Plan to harvest crops with minimal damage and follow procedures to keep crops dry
- Fungicide application (for control of disease in the daughter crop) can take place either at loading or unloading

Post-harvest

PROCESSING:

- Maintain warm temperature at 10–15°C after harvest to ensure any damage is fully cured
- Only lower temperature very gradually (max 0.3°C/day) once curing is complete
- In crops at high risk of sweetening, keep temperatures high (10–13°C) for first weeks of storage (pre-conditioning), where disease levels and sprouting permit
- Monitor fry colours and sprouting regularly

FRESH/PRE-PACK:

- Curing and pull-down strategy depends on final market and likelihood of disease development
- In general, curing will be required for damaged crops or skin-spot-susceptible varieties, whereas it can be omitted if preventing development of silver scurf and black dot is essential

- Aim to pull down temperatures at c.0.5°C per day. Prevention of condensation is important

SEED:

- Seed crops will generally require dry curing
- Protracted loading period and multiple stocks/varieties in different physiological states mean condensation risk is high (high temperature differentials between stocks are common).
- Risks reduced by regular positive ventilation
- As access to stocks is often required throughout storage, individual letterbox 'lanes' that can be switched on and off are preferred

Holding

PROCESSING:

- Holding temperature (range 6–11°C) depends on use, variety and storage duration. The lower end of the scale is appropriate for 6–9 month storage; the higher end should be used for shorter durations
- Daily, controlled flushing with fresh air required to prevent build-up of CO₂
- It is imperative that sprouting is avoided (in preparation for sprouting, tubers will convert starch to sugars and fry colour will be adversely affected) and application of sprout suppressant (e.g. DMN) will be necessary for long-term storage
- Following best practice guidance is essential to avoid exceeding maximum residue levels. Holding temperatures which are lower than recommended, often as a result of prolonged periods of low ambient temperature

FRESH/PRE-PACK:

- Holding temperatures vary from 2–5°C, depending on variety, market, storage duration and fridge capabilities
- A sprout suppressant will be required in warmer-temperature stores
- Ethylene is an option for fresh market. Introduce treatment gradually to minimise any stress on the crop. Consult with your ethylene specialist prior to use

SEED:

- Prevention of sprout growth is important and requires the use of refrigeration, especially for storage after Christmas
- A holding temperature of 3°C is often used to hold crops through to when seed is removed from store in the spring
- Airflows may differ from fresh storage because seed is generally small and packs together more tightly within a box
- As grading takes place, ensure main doors within refrigerated holding store stay closed whenever possible to reduce the risk of condensation

Unloading

PROCESSING:

- Poor fry colour at this stage is usually the result of one of two things:
- Low-temperature sweetening – this may be alleviated by reconditioning (storing at c.15°C prior to unloading to increase respiration and 'burn off' sugars), although this is very variable and further advice should be sought on a case-by-case basis
- Senescent (old-age) sweetening – this is largely irreversible

FRESH/PRE-PACK:

- Aim to warm crop (>8°C) before unloading to reduce damage
- Warmed crops should be stood to equilibrate for a day; this allows skins to become more elastic and reduces 'thumbnail' cracking

SEED:

- Aim to warm crop (>8°C) before unloading to reduce damage
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